

Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. Red Delicious

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Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. Red Delicious

Shaiq Ahmad Ganai
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Thesis

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2013

“Parents”

Someone who hold me in arms as I enter this world

Someone who encourages all my efforts and appreciate me wholeheartedly

Someone who listens patiently to my never ending doubts

Some who's eyes shine with pride and happiness at my every little achievement

Someone who helps me to smile instead shedding a tear

Someone who is our life-long friend

DEDICATE MY THESIS

To

Noble Minds :

Dr. Ashraf Ganaie

Dr. Hafiza Ahsan

Dr. Sajad M. Wani

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Certificate – I

This is to certify that the thesis entitled, **“Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. Red Delicious”** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Post Harvest Technology)**, to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Shaiq Ahmad Ganai (Regd. No. 2010-305-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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This is to certify that the thesis entitled, “**Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. Red Delicious**” submitted by **Mr. Shaiq Ahmad Ganai**(Regd. No. **2010-305-D**), to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Post Harvest Technology)** was examined and approved by the Advisory Committee and External Examiner on

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Stored Apple cv. Red Delicious**

ABSTRACT

The present investigation on “Effect of harvest dates and post harvest treatments on quality and shelflife of stored apple cv. Red Delicious” was carried out in the Division of Post Harvest Technology, SKUAST-Kashmir during the year 2011-2012. Fruits from three harvest dates (H₁, H₂ and H₃) were subjected to various treatments. The treatments included T₁ (shade cooling), T₂ (Hydrocooling), T₃ (Hydrocooling + calcium chloride), T₄ (Hydrocooling + wax) and T₅ (Hydrocooling + calcium chloride + wax). Samples were stored under ambient and refrigerated condition for 100 days to monitor various quality changes. Among physical parameters, fruit length, fruit diameter, fruit weight, fruit firmness decreased with increase in storage period while as rot incidence and physiological weight loss increased. L/D ratio showed non-significant changes during storage. There was colour degradation as indicated by increase in L* and b* values and decrease in a* values during storage. In general T₅ (Hydrocooling + CaCl₂ + wax) showed lowest changes in all the studied parameters and T₁ (shadecooling) showed highest changes.

Like physical parameters, chemical parameters also showed both increasing and decreasing trends. There was a decrease in moisture content, acidity, juice content, pectin and ascorbic acid during storage while as TSS, total

sugar and calcium content increased during storage of 100 days. Changes were more pronounced in ambient storage than refrigerated. Anthocyanin first increase and then decrease through out the storage while as polyphenol content showed no changes initially and later on got decreased with storage. Polygalacturanase activity increased from 9.33 to 18.13 per cent in ambient storage and from 9.39 to 14.90 per cent in refrigerated storage where as methylpectin esterase activity increased from 30.32 to 49.43 $\mu\text{m}/\text{litre}/\text{hour}$ in ambient and 30.32 to 34.81 $\mu\text{m}/\text{litre}/\text{hour}$ units in refrigerated condition.

Sensory analysis showed that there is continuous decrease in texture, flavour and over all acceptability during storage. However colour did not show any change during initial period of storage and decreased later. Economic analysis as studied by using returns on treatment revealed that T₅ is superior to all other treatments.

Key words : Apple cv. Red Delicious, Polygalacturanase, methylpectin esterase, polyphenol, pectin, colour (L*, a*, b*)

Signature of the Student

Signature of Major Advisor

Dated_____

Dated_____

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Place : Shalimar, Srinagar

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Chapter – 1

INTRODUCTION

Apple (*Malus domestica* Borkh.) is one of the most important tree fruit of the world belongs to the family Rosaceae and sub-family Pomoidae. The apple was cultivated in Greece around 600 BC or earlier (Jan *et al.*, 2011). Apple is a typical temperate tree fruit with more than 80 per cent of the world's supply being produced in Europe. The major apple producing countries of Europe are Italy, France and Germany. Other countries which have a marketable production of apple include USSR, China, India, Iran, Turkey and several other countries. Total apple production in the world is approximately 4.0 million tonnes (Anonymous, 2011).

From nutritional point of view its importance in daily diet is evident from an old saying “an apple a day keeps the doctor away”. It reduces the incidence of dental caries, helps to control the obesity and supplies extra energy for heavy exercise. It is highly nutritive fruit which is a rich source of sugars (11%), fat (0.4%), proteins (0.3%), carbohydrate (14.9%), vitamins and minerals. A 100 g fresh apple contains 0.8 g fibre, 0.3 g ash, 8 mg/100 g vitamin C, 3 mg/100 g sodium, 145 mg/100 g potassium, 7 mg/100 g calcium, 6 mg/100 g magnesium, 4804 µg/100 g iron, 12 mg phosphorus and 2 µg iodine (Hussain, 2001).

In India commercial cultivation of apple is largely confined to the state of Jammu and Kashmir, Himachal Pradesh and Uttrakhand which together accounts for about 2.5 per cent of world production. In the State of Jammu and Kashmir apple constitutes bulk of fruit crops and occupies about 2.05 lakh ha. The state produces 77 per cent of the total production in the country with the productivity of 10-12 t ha⁻¹ (Anonymous, 2011).

Among the various varieties of apple grown in the valley “Red Delicious” occupies major area under cultivation and is considered as an excellent commercial variety because of its overall quality, flavour and juice content.

Harvesting time is an important determinant for storage life. Fruits harvested at advanced maturity are more prone to mechanical injury, have short storage life and greater susceptibility to pathogens and physiological disorders (Juan *et al.*, 1999). In addition, careless harvesting characterised by immature and over mature fruit, is another serious cause of postharvest losses (Ingle *et al.*, 2000). Being a climacteric fruit, apple can be harvested at physiological maturity (Roth *et al.*, 2005), stored to catch good price in the market (Sayin *et al.*, 2010). In general, apple fruit harvested at immature stage have poor colour and flavour and more susceptible to physiological disorders such as bitter pit and superficial scale (Kader and Mitchell, 1989; Kvikliene *et al.* 2008). By contrast fruit harvested over mature tend to be soft and easily damaged during postharvest operations (Ingle *et al.*, 2000). Such fruits are more susceptible to diseases and physiological disorders as well as quality deterioration during or after storage (Ingle *et al.*, 2000; Hribar *et al.*, 1996).

Pre-cooling by removing field heat from freshly harvested fruits reduces microbial activity and respiration rates. Furthermore, the respiratory activity and senescence of fruit as well as ethylene production are temperature dependent. Due to the pre-cooling treatments, metabolic activity and consequently respiration rate and ethylene production of the fruits is reduced considerably. This also decreases the ripening rate, diminishes water loss and decay, thus helps preserving quality and prolongs shelf-life of the fruit (Ferreira *et al.*, 1994).

Several physiological disorders and diseases of apple fruit during storage are related to the calcium content of fruit (Huder, 1981; Shear, 1975). Calcium deficiency results in economic losses in fruit (Dyson and Digby, 1975; Wilkinson and Fidler, 1973). It helps in regulation of metabolism in apple fruit, and adequate concentration maintain fruit flesh firmness and minimize the incidence of physiological disorders like water core, bitter pit and internal breakdown (Bangerth *et al.*, 1972; Faust and Shear, 1968). The increase in calcium generally delays the ripening of the fruit and maintains their quality during prolonged

storage. The application of calcium also reduces the incidence of storage decay (Conway, 1982; Sharples and Johnson, 1977).

Coating apples prior to storage seems an excellent fit for “Red Delicious” because it imparts high gloss, hides bruises and forms a modified atmosphere condition that tend to preserve firmness and prolong shelf-life. The inhibition of biochemical processes, which cause the aging of apples and shortening of their storage, may be achieved with the help of natural and artificially made chemical substances, which are used for after harvest treatment for fruits (Alleyne and Hagenmaier, 2000; Bai *et al.*, 2002).

Apple fruits are kept in cold storage after harvest to preserve their quality, low temperature plays main role in slowing the degradation of apple fruit quality during storage. Apples like other climacteric fruits display abrupt increase in ethylene production during ripening that lead to change in texture, fruit flesh firmness, colour etc. Endogenous ethylene plays key role in apple softening and rapid fruit softening is associated with a rapid rise in ethylene production (Nilsson and Gustarsson, 2007). The low storage temperature offers the prospect of preventing or delaying softening and improving the texture and quality of fruit available to consumers (Golias and Letal, 1995).

The data available with national Horticulture Board (NHB) indicate that 30 percent of fruits produced are lost due to mismanagement and in case of apple the loss percentage is 10-25 per cent from total production (Anonymous, 2007).

Moreover due to inappropriate postharvest management practices, lack of proper scientific storage and transportation facilities in the state of J&K, post harvest losses of 20-40 per cent results during harvesting, handling, packaging, transportation, marketing and storage (Ghani *et al.*, 2003).

Under agro-climatic conditions of Kashmir valley the apple fruits var. “Red Delicious” matures in 2nd week of October. The fruits are manually harvested, packed in wooden boxes and without any postharvest treatment are

send to market outside the state. There is a mismatch between fruit supply and demand in the markets which leads to lower price of the fruit and the consequent less income to growers. Further on account of progressive ripening changes the fruit loses its acceptable quality parameters in very short time during blockage of the national highway due to which huge losses occur.

In Kashmir valley less awareness is available among the growers regarding the exact harvesting time, pre-cooling, postharvest treatments and storage conditions for enhancing the shelf life of apple especially that of “Red Delicious” cultivar. Therefore, keeping in the view the above facts, the present investigation was aimed to improve shelf life and quality of apple by working out appropriate harvesting date, pre-cooling and various postharvest treatments with following objectives :

- 1) To assess the combined influence of harvest dates and postharvest treatments on quality and shelf-life of apple cv. “Red Delicious” during storage.
- 2) To study the changes in biochemical attributes of treated apple during storage in relation to harvest dates.
- 3) To asses suitable harvests date along with storage treatments for market regulation and better returns.

Chapter – 2

REVIEW OF LITERATURE

2.1 Harvest Date

Gherghi *et al.* (1977) concluded that in Jonathan, total losses during storage, including weight loss and loss from rotting, were least following harvesting 132 days after flowering and in Golden Delicious, “Red Delicious” and Starkrimson following harvesting 150 days after flowering. Organoleptic characteristics and chemical changes as well as storage losses, it was established that the best time to harvest Jonathan was 140 days after flowering, when starch content in the surface of a transverse section of the fruit was 75 per cent, while for Golden Delicious it was 145 days after flowering, when starch content was 80 per cent, and for “Red Delicious” and Starkrimson it was 150 days after flowering, when starch content was 75 per cent.

Vishanska and Barov (1981) harvested apple cvs “Red Delicious”, Jonathan and Tetovka each on 3 dates at 10-14 days intervals and stored at 0-1 °C and 85-90 per cent RH. Fruit harvested on the optimum date had the lowest amount of wax-free membrane, which can be used as a criterion for assessing harvesting maturity. A 10-day delay in harvesting did not, however, result in destructive changes in the cuticular components of cold stored fruit.

Olsen (1982) reported that the fruits approaching harvest often show a sudden drop in firmness and an increase in soluble solids and starch breakdown. Variation of some measurements within the fruit (firmness, soluble solids, color) and within the tree should be considered when sampling and monitoring harvesting (Shaw and Rowe, 1982; Kupferman, 1986).

Maturity indices currently available to the industry include fruit size, flesh firmness, soluble solids, titratable acidity, starch breakdown (iodine test), seed color, respiration rate, skin color (ground and surface color), and flesh chlorophyll (Kupferman, 1983; Olsen, 1982). Calendar date, number of days from full bloom

(DFFB or DAFB), accumulated heat units and days from Tstage (Stoll, 1968) can be added to the list. None of them can be used alone, and all of them should be tested on the new cultivars in every growing location. Variation in the fruit population in the same orchard, between orchards, and from year to year has accounted for the lack of one single maturity standard (Olsen, 1982).

For economic reasons, fruit should be harvested when quality criteria can be best satisfied (Knee and Smith, 1989). Quality can be considered on external aspects-size, color, fruit uniformity, absence of blemishes, rot, spots, and on internal characteristics-texture, juiciness, flavor, aroma (Kupferman, 1983), as well as nutritional value. Finally, the time of harvest is significant because rapid changes in fruit metabolism occur close to maturity. The physiological stage at harvest can affect: 1) fruit quality as perceived by the consumer for fresh consumption, 2) fruit storage potential, and 3) fruit quality for processing. Physiological maturity of climacteric fruit can be recognized by following the rate of respiration of the developing fruit (Olsen, 1982).

Nayital and Chopra (1991) picked “Red Delicious” apple fruits at intervals from 80 to 153 days after full flowering, and stored for 180 days at $0\pm 1^{\circ}\text{C}$ and 85-90 per cent RH. At the end of the storage period, fruits picked 130 ± 2 days after full flowering had the greatest organoleptic scores, fruit firmness (4.77 kg) and percentage total soluble solids (12.37%). Fruit firmness and total soluble solids content at harvest were 8.22 kg and 12.27 per cent, respectively.

Juan *et al.* (1999) investigated the effect of harvest date on storage ability of “Golden Delicious” apple and cold stored for seven months. Quality indices (soluble solids content, flesh firmness, acidity and starch index) were determined weekly for one month before the first harvest date and upon removal from storage. Fruit susceptibility with increasing maturity was inoculated with *Penicillium expansum*, keeping in cold storages for five weeks. After removal from cold storage, superficial scald and moisture loss incidence were higher on fruit picked earlier. Bitter pit occurrence was also observed. The percentage of marketable size

fruit and disease severity increased with harvest date. Starch index was significantly correlated to acidity, soluble solids and firmness, suggesting that it could be used to predict fruit quality after cold storage.

To ensure maximum storability, apples should be picked when mature, but not fully ripe. If apples are picked when they are too ripe, physiological processes are underway which complicate storage, even under optimal conditions (Ingle *et al.*, 2000). Apples picked at right stage have the organoleptic qualities which enable them to survive more than six months of storage. Apples which were harvested the earliest were firmest both before and after storage, but lost a greater percentage of their firmness during storage. Apples harvested 100 days after full bloom (DAFB) had a firmness of 10.2 kg at harvest and 5.0 kg after storage, and lost 51% of their initial firmness. Apples harvested 128 DAFB had a firmness of 8.2 kg at harvest and 4.7 kg after storage, and lost 43 per cent of their initial firmness. Apples harvested 114 and 21 DAFB lost only 41 per cent of their initial firmness. This agrees well with an earlier study on fruit softening in other cultivars (Meresz *et al.*, 1993). Fruits that are picked before physiological maturity will not ripen satisfactorily (Robertson *et al.*, 1990), while those harvested at more mature stage have shorter shelf life (Meredith *et al.*, 1989) and did not ship well because of reduced shelf life (Murray *et al.*, 1998).

Erkan and Pekmezcu (2004) studied the effect of harvest dates (15 days interval) on superficial scald development and postharvest quality in “Granny Smith” apples (*Malus domestica*) stored at 0°C with 90 per cent relative humidity for 8 months. A significant variation was observed for weight loss, soluble solids, titratable acidity and flesh firmness among the different harvest dates. Increased soluble solids were achieved with Delay harvest. Flesh firmness, titratable acidity and soluble solids remained at acceptable levels regardless of harvest dates and storage durations. Early harvested fruits were decayed at a lower rate. The “Granny Smith” apples could be stored for 8 months with minimal scald incidences (0 to 14.2% depending on storage length).

Nabiaeck and Ben (2004) harvested apple (cv. Gala Mast) fruits in 3 terms at 7-day intervals during 1997-99 in Poland, where the optimum harvesting date was established between 129 and 136 days after full flowering. The fruits harvested in the first term had lower weight and diameter than the fruits in the second term. On the other hand, the fruits harvested in the second term had the highest firmness (7.2-7.6 kg) and organic acid content (0.28-0.30%) after 180 days of cold storage at 0 degrees C and after an additional 7-day storage at 18 degrees C.

Maturity at harvest has a very important influence on storage life and the compositional quality of apple fruit. However, the 'optimum' harvest date is dependent on the cultivar, the planned use of the fruit, the given storage technology and the marketing strategy (Tromp, 2005; Wertheim, 2005). In early harvested apples quality is low but storability is high, whereas late picked apples have a high sensory quality but reduced storability (Tromp, 2005). In most apple varieties ethylene production increases markedly during the harvest period. The plant hormone ethylene influences many of the ripening processes and the increased production leads to improved quality (flavour, aroma) but decreased storability (softening). Harvest maturity indices (e.g. 'Streif-index') which use a combination of different ripening and quality characteristics such as flesh firmness, starch index and soluble solids concentration, can be calculated for determining the optimum harvest date with respect to cultivar, storage regime and duration (Wertheim, 2005; Hewett, 2006). In order to harvest all fruits at the right time, i.e. at the optimum stage of maturity, sequential picking is recommended (Kingston, 1992; de Jager, 1994). Harvesting of apple fruit is generally carried out by hand. Physical damage due to mechanical injuries such as bruising, surface abrasions and cuts (Lee and Kader, 2000) lead to a loss of quality and storability and should be minimized by proper harvest management. Moreover, postharvest fruit quality is influenced by harvesting method, transport and handling conditions, storage conditions and conditions in retail. McLellan *et al.* (1990)

harvested apple fruits at three different stages. The harvested fruits were at cold storages with a 95 per cent RH. The slices of apples were taken from different treatments for analyzing their Brix/acid ratio. Raw slices of apples were analyzed through Sensory analysis. Slice firmness was due to CA delay and harvesting date. With the delay of storing at CA storage the un-blanching raw slices, showed softening, while late harvest also resulted higher softening. Blanching of slices greatly increased the softening. A significant increase in apple flesh browning was recorded at delay in storage at CA and due to later harvest. There was no significant difference in acceptability rating of raw slices of apples before freezing.

Kvikliene *et al.* (2006) evaluated the pre and post-harvest chemical changes in apple cultivar “Auskis”. Least weight loss was observed in apple cultivar harvested at optimum maturity. Fruit firmness was decreased with late harvesting. Positive correlation was observed between firmness at harvest and post-storage acidity and negative correlation was observed in firmness at harvest and post-storage sugar/acid ratio. Post-storage sugar/acid ratio and post-storage soluble solid content were correlated to soluble solids content at harvest. They reported that optimal harvest time is in between of 114 and 121 days for apple cultivar “Auskis” after full bloom.

2.2 Pre cooling

Velkov (1982) cooled two apple cvs in water until the core temperature was 5 deg C, and then cold stored at 0 deg and 92 per cent RH. After 6 months’ storage, losses due to rots in “Red Delicious” apples were lower than uncooled fruit.

Brackmann *et al.* (2004) studied the effects of cooling, fruit temperature (FT), and relative humidity (RH) during storage on the quality of apple. The treatments consisted of: air precooling + 5 degrees C FT + 96 per cent RH (T₁); air precooling + 15 degrees C FT + 96 per cent RH (T₂); air precooling + 5

degrees C FT + 90 per cent RH (T₃); air precooling + 5 degrees C FT + 96 per cent RH (T₄); and hydrocooling + 5 degrees C FT + 96 degrees C (T₅). After 8 months of storage, flesh firmness was greatest in T₃ fruits. T₄ resulted in a higher incidence of peel yellowing, internal breakdown and mealiness. After 7 days at 20 degrees C, T₃ fruits showed a lower incidence of decay.

Silva *et al.* (2006) compared the performances of water and air used as heat sink fluids in apple cooling. The water system was shown to perform twice as fast as the air system under comparable conditions.

2.3 Calcium chloride

Maini *et al.* (1983) treated fruits of “Red Delicious” with 4 per cent CaCl₂ for 15 minutes and held at 15 to 16°C and 35-49 per cent RH for up to 25 days. Physiological weight loss and reduction in other quality indices were generally lower in treated fruits.

Mir *et al.* (1993) harvested fruits were dipped for 5 min in 0, 1, 2, 3 or 4 per cent CaCl₂ solutions, air dried and stored under ambient conditions for 60 days. Dipping in CaCl₂ solutions reduced the rate of loss of fruit firmness and weight during storage. These effects increased as the CaCl₂ concentration increased.

Badshah *et al.* (1994) collected fruits of the apple cv. “Red Delicious” from the main market in Peshawar, dipped for 2 min or sprayed with calcium chloride at 0, 1, 2, 4 or 8 per cent, then placed in cold storage at 38 °F, 92 per cent RH for 4 months. Changes in TSS, total acidity, vitamin C and total sugars during storage were all reduced with increasing concentration of calcium chloride; the decreases in total acidity and vitamin C were significantly reduced by 8per cent compared with 4 per cent calcium chloride.

Bhartiya *et al.* (1998) showed effects of postharvest dips with CaCl₂ or s (0.5, 1.5 or 2%), or CaCl₂ + S (0.5%) on the quality of apple cv. “Red Delicious” fruits during storage at 10°C were investigated. After 90 days of storage the

lowest physiological loss in weight was noted following CaCl₂ (2%) treatment. The highest flesh firmness and acid contents were recorded following treatment with S (0.5%). The application of CaCl₂ (0.5%) + S (0.5%) showed the highest sugar and TSS contents after 90 days of storage; fruits from this combined treatment scored the highest organoleptic ratings after storage. At the end of storage, fruits treated with CaCl₂ (1.5%) had the most intense colour.

Trentham (2008) stored the apple fruits at 0°C after dipping for 2 minutes in 0, 2, 4, or 6 per cent solution of CaCl₂ at 0 or 68.95 kPa. He recorded the data for different parameters with the interval of four months. Paraffin sections were stained with an aqueous mixture of alcian blue 8GX, Safaranin 0 and Bismark brown Y, or with the periodic acid-Schiff (PAS) reaction. No histological difference was observed in fruit treated with 2 per cent CaCl₂ compared with those pressure-infiltrated with greater amounts of Ca. Fruits pressure-infiltrated with 6 per cent CaCl₂ exhibited the greatest amount of flattened epidermal cells and hypodermal cavities. Cuticles were also affected at the higher CaCl₂ treatment levels (with regard to staining with Bismark brown), becoming more condensed and uniform. Cuticle and hypodermis were stained differentially with PAS in the 6 per cent CaCl₂ treatment. All tissues, including the cuticle, were stained magenta red, indicating a possible chemical alteration of the cuticle and the underlying tissue by calcium.

Shirzadeh *et al.* (2011) showed that fruit weight loss significantly decreased in calcium treatments in comparison to control. Also, results showed that calcium treatments increase fruit firmness, catalase activity, TA and Perlim index, while decreasing of pH, TSS/TA ratio and peroxidase activity during cold storage at 0 to 2°C for 5 month ($P \leq 0.05$). The results showed that calcium treatments application was influenced on ethylene in comparison to control. Post-harvest Ca treatments prevented fruit softening and decreased weight losses.

Hussain *et al.* (2012) dipped freshly harvested “Red Delicious” apples in calcium chloride solution of varying concentrations (0.5–2.0% w/v) for 1 h prior

to irradiation at dose level of 0.4 kGy. Results revealed significant ($p \leq 0.05$) retention in firmness, juice yield and ascorbic acid content in samples treated with combination of calcium chloride at 2.0% w/v and gamma irradiation (0.4 kGy) during storage. Water soluble pectin was inversely correlated with firmness ($r=0.88$) and was significantly ($p \leq 0.05$) lower in samples subjected to combination treatment of 2.0% w/v CaCl_2 and 0.4 kGy irradiation throughout the storage. The combination treatment of 2.0% CaCl_2 and 0.4 kGy irradiation gave about 4.3 log reduction in yeast and mold count of apple samples. Results of the post refrigeration weight loss, firmness and overall acceptability revealed that combination treatment was helpful in extending the shelf-life of “Red Delicious” apples by around 20-25 days at $17 \pm 2^\circ\text{C}$, RH 75 per cent following 90 days of refrigeration.

2.4 Coatings used

Wax coatings were developed to mimic the natural coating of fruits and vegetables. Coating of fresh citrus fruits with wax to extend their shelf life can be traced back to 12th to 13th century China (Hardenburg, 1967).

Gorini and Mori (1972) harvested apples at the beginning or end stage of commercial ripeness, treated with 2 per cent lecithin or 2 per cent vegetable wax, and refrigerated immediately, or after 2 weeks. Neither surface treatment reduced spot, and waxing increased the percentage of rotted fruit. Immediate refrigeration, however, reduced spot considerably.

Singh (1973) investigate the effect of tissue paper and polyethylene wrappers, wax coating and wax + tissue paper on the storage quality and composition of “Red Delicious” and Golden Delicious apples stored at an altitude of 3500 m (at temperatures down to -20°C) for 7 months. “Red Delicious” kept better than Golden Delicious. Polyethylene was the best wrapping material, as indicated by the least fruit rotting, shrivelling and weight loss. However,

polyethylene-wrapped fruit had the lowest total soluble solids and reducing sugars contents, and the highest acidity.

Another coating with similar composition, *semperfresh*, contains a higher proportion of short-chain unsaturated fatty acid esters in its formulation (Drake *et al.*, 1987). These coatings retarded colour development and retained acids and firmness as compared to controls when tested on apples (Smith and Stow, 1984). *Semperfresh* also extended the storage life of citrus (Curtis, 1988), and Valencia oranges coated with *Tal Prolong* had better flavour and lower ethanol levels than controls (Nisperos-Carriedo *et al.*, 1990). By adding waxes to *Semperfresh*, the coating gave a better shine and fruits had higher turgidity, less decay and good flavour. On the other hand, *Semperfresh* was not effective in retarding water loss of melons (Edwards and Blennerhassett, 1990).

Singh *et al.* (1991) coated Apple fruits with 8 per cent waxol-w-emulsion containing 0.4 per cent sodium orthophenylphenate for 30-60 s or packaged in 200 gauge polyethylene bags provided with 0.2, 0.4 or 0.8 per cent ventilation. All treatments were effective in extending the shelf life of apples by about one week compared with the controls. Packaging resulted in improved colour and gloss during storage compared with wax coating and control.

Mahajan and Chopra (1992) investigated the effect of postharvest application *frutox* (wax coating) on the quality and storage of apples and found 6 per cent *frutox* was most effective treatment for reducing physiological weight loss, percentage rot, breakdown of flesh firmness of stored apples and for improving fruit quality. Peaks of ethylene evolution and respiration rates were lower than untreated control. Overall this treatment was effective in slowing down the metabolic rates of apple fruits and prolonging their shelf life by 30 days or more compared with untreated control fruits.

Commercial use of wax preparations is fairly extensive on apples, citrus fruits, mature green tomatoes, cucumbers and rutabagas (Swedes), and has been

tried on a limited basis on many other fruits and vegetables (Krochta *et al.*, 1994). Many coatings used today are similar to those used in the past. The wax type coatings are made with natural or synthetic waxes (carnauba, polythene) plus oils, wood rosin, shellac, surfactants and preservatives. All of the coatings reduce water loss, add various degrees of sheen, and provide adequate permeability to CO₂ and O₂. Coatings with shellac and rosin, however, have lower permeability to CO₂, O₂ and ethylene, while coatings made with polythene have higher gas permeability than those from Carnauba (Nussinovitch and Lurie, 1995).

Hayat *et al.* (2003) investigated the effect of different concentrations of calcium chloride (1, 1.5 & 2%), paraffin wax coating and different wrapping materials (polyethylene, carton paper) to increase the shelf life and to avoid the postharvest losses of Banky cultivars of apple. All the treatments had a significant effect on the shelf life of fruits. Calcium chloride (2%) proved very useful for reducing weight loss and shrivelling and retained consumer acceptability even after 60 days of storage. Polyethylene packaging stood second position after 2% calcium chloride treatment.

Sabir *et al.* (2004) reported that chemical treatment, wax coating, oil dipping and different wrapping materials have significant role in extending the shelf life of apple. Non-perforated polyethylene was reported superior to all other treatments. Non perforated polyethylene materials proved very useful for reducing weight loss and shriveling and retained consumer acceptability even after 60 days of storage. Hydroxyquinoline and butter paper wrapping stood second and third positions after non perforated polyethylene wrapping.

Mir *et al.* (2004) treated apple cv. "Red Delicious" after harvest at commercial maturity stage with wax coating materials stay-fresh; sta-fresh (1:1), virosil-agro (2.5%) or dipped in calcium chloride (4%) for 10 minutes. Quality evaluation during storage indicated that among treatments stay-fresh and sta-fresh (1:1) coating proved to be effective in reducing starch hydrolysis; physiological weight loss and texture break down. Sensory panel evaluation exhibited "fair to

good” acceptability response of stay-fresh or sta-fresh coated apples upto 65 days of storage on basis of firmness, juiciness and flavour quality attributes, where as in control lots the quality attributes showed maximum acceptability scores only upto 45 days under ambient conditions.

Pandit *et al.* (2007) used different postharvest treatments such as wax dip and gibberellic acid at 500 ppm, with perforated polythene (PP), high density polythene (HDPE) and low density polythene (LDPE) wrappings to apple cv. “Red Delicious” fruits. GA (500 ppm)-treated fruits wrapped in HDPE bags proved the best over all the other treatment tried. The results indicated that 500 ppm GA treated fruits in HDPE bags can be stored up to 56 days with an excellent appearance quality and were adequately edible and marketable.

Worakeeratikul *et al.* (2007) found the effects of chitosan coating on browning and physiological changes in fresh-cut rose apple (*Syzygium jambos*). Cooled fruits were cut into four sections and treated with chitosan (4 degrees C) at 0 (control), 0.05, 0.1 and 0.2% (v/v), wrapped with polyvinyl chloride film and stored at 5 degrees C for 72 h. Chitosan retarded browning, maintained the L value, total soluble solids, reducing sugar content and titratable acidity compared to the untreated sections. Chitosan coating had no significant effects on the changes of flesh colour (b value), phenolic content, polyphenol oxidase [catechol oxidase] activity and flesh texture.

Wijewardane and Guleria (2009) find out the natural and ecofriendly fruit coating, package and storage alternatives for the extension of the storage life of apple (*Malus domestica*) cv. ‘Royal Delicious’. Surface coating of apple with 1, 1.5, 2 per cent neem oil (*Azadirachta indica*) and 10, 15, 20 per cent extracts of marigold flower (*Tagetes erectus*), along with pre-cooling were tested on the storage quality of the fruit. The results revealed that, surface-coating of apple with 1.5-2 per cent concentration of neem oil along with pre-cooling was the most effective in providing better physico-chemical umbrella, effectively lowering fruit softening and PG enzyme activity, and significantly lowering fruit spoilage during

storage. Similarly, packaging of fruits with corrugated fiber board (CFB) boxes + paper mould trays, CFB + Polyethylene (PE) liners and shrink-wrapped tray packing during storage ($2\pm 1^{\circ}\text{C}$ and 85-90% RH), showed that the surface-coating of apple with 2 per cent neem oil together with shrink-wrapped tray packing provided better retention of storage life of fruit and the treatment effect on physico-chemical characteristics of fruits were significant.

2.5 Temperature management

It is generally accepted and often described that ethylene plays a critical role in apple ripening (Abeles *et al.*, 1992; Gorny and Kader, 1996; Mathooko, 1996). Therefore, suppression of ethylene biosynthesis and action is the main concern of postharvest strategies. The most simple and effective means of controlling ethylene production and reducing the overall metabolism is achieved by storage at low temperatures (Lurie, 2002 and Kader, 2003). Low temperatures considerably reduce respiration (Lee *et al.*, 1995; Wills *et al.*, 2007) and it is described that both enzymes involved in the ethylene biosynthetic pathway, ACC-S and ACC-O are sensitive to low temperatures (Larrigaudiere *et al.*, 1997). Moreover, tissue sensitivity and the rate of ethylene biosynthesis are dependent on temperature (Lee *et al.*, 1995; Wills *et al.*, 2007). At lower temperatures fruit are less sensitive to ethylene and at a given ethylene concentration it takes longer until response, i.e. ripening is initiated. Moreover, it has been described that loss of vitamin C is generally reduced at lower temperatures (Paull, 1999) and low temperatures also reduce fungal infection and decay during apple storage (Lee *et al.*, 1995; Lurie, 2002). The fact that respiration generally releases heat is another important reason for storage at low temperatures (Lurie, 2002; Wills *et al.*, 2007). In general, low temperatures significantly delay the initiation of ripening and clearly decrease all metabolic activities and biochemical reactions during ripening in harvested fruit (Kingston, 1992; Lee *et al.*, 1995). Apples are ideally stored at temperatures just above the freezing point, depending on the variety and the sensitivity to ‘chilling injury’ (Johnston *et al.*, 2002; Wertheim, 2005; Wills *et al.*,

2007). Too high temperatures generally result in faster ripening and in turn in shorter storage life whereas too low temperatures might induce physiological disorders and ‘chilling injury’ (Lee *et al.*, 1995). It is important to rapidly cool apples after harvest. The quicker the optimum storage temperature is achieved, the better the maintenance of fruit quality and the longer the storage life (Paull, 1999; Wertheim, 2005; Wills *et al.*, 2007). Therefore, an appropriate temperature management after harvest is the most important factor in maintaining fruit quality, delaying ripening of climacteric fruit and extending and improving storage- and shelf-life (Lee *et al.*, 1995; Lee and Kader, 2000; Lurie, 2002).

The majority of apples must be consumed within a relatively short time after harvesting; otherwise there will be high rotting losses due to the biological properties of the fruit. Apples, which consist of living tissues, are submitted to continuous post-harvest processes, resulting in senescence and death (Kader, 1999). Since inhibition of these processes is not possible, decreasing the rate of them is an important task. Thus, the objective of storage is to prolong the life of the fruit tissues by slowing down the metabolic processes within the fruit that influence its age. Such metabolic processes include in particular respiration intensity and internal ethylene production (Paull, 1999). High storage temperature or low relative humidity or both reduce storage potential, decrease apple quality and enhance disorders (Paull, 1999).

2.6 Storage changes

Dzonova *et al.* (1972) found that in “Red Delicious” apples total sugars and fuctose increased at first but decreased during the later months of storage.

Bebic (1972) reported that weight losses in cold-stored apples were directly related to skin characteristics, primarily the thickness of the epidermis and the surface wax, and to the number of lenticels. During 6 months storage at 0-1 deg C and 85-90 per cent R.H. weight losses in Golden Delicious were 6.15 per cent, in Jonathan 5.08 per cent and in “Red Delicious” 3.30 per cent.

Kolev (1973) stored “Red Delicious” and Golden Delicious apples at temperatures of 0 to -2 deg or 0 to + 2 deg C and RH of 85 to 90 per cent, in open wooden boxes or packed with 60- to 80- mm-thick polyethylene film and arranged in pallet boxes. The fruits of all cvs studied retained their initial quality when packed with polyethylene and kept at 0 to -2 deg. Storing in open containers brought about greater weight losses, which were considerable at both the beginning and the end of the storage period. Fruits kept in polyethylene suffered greater weight losses during the second month and at the end of storage (March). The flesh density of Golden Delicious declined little during storage from September to March, whereas in “Red Delicious” it was reduced by one half.

Bartram (1976) observed changes in the flesh firmness of Starking “Red Delicious” apples harvested 145 or 165 days from full bloom and stored at 31 deg or 32 deg F until late April. The fruit softening was least rapid in earlier picked fruit stored at 31 deg.

Panait (1979) studies were carried out with Jonathan, Golden Delicious, “Red Delicious” and Starkrimson apples stored at 3 deg C and 90 per cent RH from October to May. Total sugars, particularly glucose, accumulated gradually during storage although sucrose declined, especially in April. The total sugars/sucrose ratio, used as an index of apple marketability, showed that Jonathan and Golden Delicious kept well until March, Starkrimson until late April and “Red Delicious” (with the best storability) well beyond April.

Dzetsina and Sharova (1985) found that dry matter (DM) content decreased during storage, particularly when stored in the plastic packs and Sucrose content showed greater variation. In general, dry matter increased in the first 30 days of storage.

Gupta *et al.* (1987) harvested fruits on 28 Sep. and packed in conventional wooden boxes with paper linings were held at room temperature for 24 h, or for 1, 2 or 4 weeks before storage at 0-1°C and 85-90 per cent RH. All fruits were

withdrawn from cold storage on 15 Apr. and tested for shelf life over 3, 10, 17 and 24 days. Only fruits cold-stored immediately after harvest were commercially acceptable after 17-24 days of shelf life.

Joshi *et al.* (1988) experimented medium-sized fruits, grown in an orchard were packed in traditional wooden boxes or in corrugated cartons, each containing 8 or 15 kg, and transported to Lucknow (482 km). The lowest fruit weight loss (3.35%) and least spoilage occurred in the corrugated cartons with 15 kg capacity, closely followed by the 8-kg cartons, and the greatest losses and damage occurred in the 15-kg wooden boxes.

Prakash *et al.* (1985) found that fruits of “Red Delicious” harvested at optimum maturity (a starch pattern index of around 4) and held at 32°F and 90 per cent RH for 3-5 months showed good quality and storability.

Gupta *et al.* (1989) graded Apples cv. “Red Delicious” into 3 sizes: small (diameter <69 mm), medium (70-79 mm) and large (>80 mm). Small- and medium-sized apples maintained their quality (with respect to physiological, biochemical and organoleptic characters) for up to 24 days. Large apples remained of acceptable quality for only 3-10 days.

Examination of fruit picked at different stages after storage is necessary to complement maturity studies. Firmness after storage has been correlated with DFFB and starch breakdown 80 per cent of the time, with soluble solids at harvest 70 per cent of the time on “Red Delicious” (Ingle and D'Souza, 1989). Fruit quality was affected by harvest date, but none of the maturity indicators tested could predict apple quality after storage (Knee *et al.*, 1989). Correlations between starch and firmness at harvest were lost after storage, indicating that starch at harvest would not predict further firmness changes (Knee *et al.*, 1989). However, the firmness of fruit after storage correlated with the firmness at harvest and the position of the fruit on the climacteric curve (Knee *et al.*, 1990). Experience shows that the later picked fruit had the most desirable dessert quality soon after

harvest, but as the storage season progressed, preference shifted towards the earlier picked fruit (Olsen, 1982). Maturity studies have often been complemented with taste panels in an attempt to have a measurable parameter for quality (Bidabe *et al.*, 1969; Knee and Smith, 1989; Saltviet, 1983).

Yahia *et al.* (1990) reported loss of aroma was irreversible after more than seven months of cold Storage and lack of flavor of apples might be due to early picking before the production of volatile esters, and the reduced rate of activity of all the metabolic pathways in storage.

The respiratory mechanisms are influenced by temperature. Generally a change of temperature of 10°C results in increase or decrease in reaction rates by factors of approximately 2.4 in case of apples within certain temperature extremes (Massey, 1989). Thus cooling apples from 25 to 15°C should double the life expectancy of the fruit, further cooling should quadruple life expectancy compared with that at 25°C. In general there is an inverse relation between respiration rate and storage life.

The storage or marketable life of apple can be extended by various postharvest treatments. The most important of these is temperature management and the storage conditions under refrigeration has been worked out for various apple cultivars. Controlled atmosphere technology of apples by manipulation of carbon dioxide and oxygen levels have extended storage life of apple upto 6 to 9 months. New approaches in CA technology, low oxygen and low ethylene, CA are also promising (Meheriuk, 1990).

Mahajan and Chopra (1995) dipped “Red Delicious” apples in Frutox [wax coating] (6%), diphenylamine + Frutox (1500 ppm + 6%), and water (control) for 2 min and then packed in corrugated fibreboard cartons and stored at 0±1°C and 90-95 per cent RH. Diphenylamine + Frutox was the most effective treatment in reducing physiological weight loss and percentage rotting and maintaining firmness.

Ali *et al.* (2004) stored five apple varieties in ordinary storage at room temperature of 25°C. An increase was observed in reducing sugar while a decrease was observed in non-reducing sugar and total sugars were increased with the prolonged storage condition. Acidity was non-significantly affected while total soluble solids significantly increased during storage at room temperature. A decrease was observed in Vitamin C during storage. They recommended Golden Delicious and Amri cultivars of apple for storage to fetch good market price.

2.7 Nutritional value

Nutritional quality and degree of healthful constituents of fruits are related to contents of vitamins, minerals, dietary fibre and phytochemicals with antioxidant properties, such as phenolic compounds (Kader, 2002; Awad and de Jager, 2003; Sanchez-Moreno *et al.*, 2006). Nutritional value of apple fruit is generally not a major criterion affecting purchase decision for most consumers. The nutrient composition varies depending on cultivar, preharvest environmental and cultural factors, stage of maturity at harvest and postharvest regime and duration. However, consumers are increasingly concerned about nutritional quality and health-protecting compounds in foods (Larrigaudière *et al.*, 2004; Vilaplana *et al.*, 2006).

2.8 Physical changes

Khorshidi *et al.* (2010) reported that in apple cultivars length, diameter, volume and fruit weight decreased with increase in storage temperature. They also reported that length, diameter, volume and fruit weight loss was significantly higher in fruits stored at 12°C than those stored at both 0°C and 5°C.

Trout *et al.* (1953) reported that weight loss during storage of Granny Smith (8 weeks at 60-70 °F) and Rome Beauty (19 days at 70 °F) was reduced (55-95%) of control by using waxes and castor oil, the effect being increased by

adding shellac. Paraffin wax was more effective than carnauba wax, which was more effective than bee's wax. Weight loss was however, increased by coating with emulsions of peanut oil, maize oil and lighter mineral oils, and removal of natural coating with alcohol.

Meheriuk and Porritt (1972) used wax preparation containing carnauba wax, paraffin and shellac for waxing of five apple cultivars viz., McIntosh, Spartan, Golden Delicious, "Red Delicious" and winesap. The waxed and control lots were stored at -1°C for 100 days. The extent of weight loss in waxed fruits varied from 1.13-2.69 per cent compared to unwaxed control (1.60-3.03%). The effect varied with the test varieties of apple.

Cohen *et al.* (1990) reported that the application of two commercial wax formulations viz., Britex or Zivdar (15 or 18%) on Murcott Tangerine fruits helped in reducing the weight loss compared to control during a storage period of 4 weeks at 0°C . Further the most successful prevention of water loss was obtained by double dips.

Koksai *et al.* (1994) treated starkspure Golden Delicious apples with 0, 0.5, 1.0 and 1.5 per cent concentrations of semperfresh solutions and stored the fruits at $0\pm 0.5^{\circ}\text{C}$ at RH 85-90 per cent. The weight loss recorded after 120 days was recorded to be lowest (8.7%) with 1.0-1.5 per cent semperfresh treatment compared to a value of 9.5 to 9.8 per cent with 0 to 0.5 per cent semperfresh.

Singh and Mohammed (1997) studied the efficacy of wax emulsion and rice starch on postharvest shelf life of guava cv. Allahabad safeda. The treatments was emulsion and rice starch significantly reduced the physiological loss in weights of fruits. The 12 per cent wax emulsion treatment recorded the minimum PLW (4.24%), followed by 6 per cent wax emulsion (5.10%) and 6 per cent rice starch without gum treatment (5.65%), where as maximum PLW (9.52%) was

observed in control. The maximum PLW (13.98%) was observed after 12 days and minimum after 4 days (4.45%) of storage.

2.8.1 Fruit firmness

Firmness in apple fruit is an important quality criterion that is used to determine storability. Firmness is largely determined by cell wall composition and structure (Mohsenin, 1970). Major changes occurring in cell wall composition of senescing apple fruit has been well characterized (Takavoli and Wiley, 1968; Knee, 1973; Bartley, 1974). These changes include a decrease in galactose and arabinose moieties of water insoluble cell wall fraction followed by increase in soluble polyuronide (Knee, 1973; Bartley, 1974).

Calcium is an important constituent of cell wall. Increasing Ca content of apple fruit through Ca treatment reduces the rate of softening (Mason, 1976; Betts and Bramlage, 1977; Scott and Wills, 1977; Johnsen, 1979) and decrease pectin solubilisation (Sams and Conway, 1984).

The effect of coating material on retardation of softening varies with the apple varieties. Meheriuk and Porritt (1972) reported that non waxed McIntosh and Spartan stored at -1°C for 100 days showed a significant difference in firmness compared with waxed fruit, but no significant differences were observed for Golden Delicious, "Red Delicious" or winesap apple varieties.

Mason (1979) reported that postharvest dips in solution containing calcium chloride reduce softening during storage. Sharples and Johnson (1980) found that vacuum infiltration generally doubled the calcium content of the fruit and delayed softening. Hardenburg and Anderson (1981) have observed that stayman apples dipped in 4 per cent calcium chloride were firmer after 5 to 6 months storage in air at 0°C than untreated fruits. Vacuum infiltrating calcium

chloride resulted in the firmest fruit after storage and the highest flesh calcium levels.

The hydrolysis of pectins is catalyzed by two groups of enzymes, polygalacturonase (PG) and pectin methyl esterase (PME) (Eskin, 1979). PG would only act on the demethylated region of the polygalacturonan, which is brought about by the action of PME. Only exo-polygalacturonase has been found in apple (Bartley, 1978). PG may be both exo- and/or endo-polygalacturonases in other fruit (Pressey and Avants, 1973; 1976). PG activity in 'Delicious' apple was undetectable until the onset of the climacteric (Liang *et al.*, 1982). It rose rapidly after harvest, and decreased gradually one month after the climacteric. Fruit softening occurred 20 days after the rise of PG activity (Liang *et al.*, 1982). The loss of firmness in apple has also been attributed to B-galactosidase activity (Bartley, 1974; Knee *et al.*, 1989 and Dick *et al.*, 1990) did not find any change in this enzyme activity during the ripening course of apple.

Maini *e al.* (1983) treated "Red Delicious" apples with 4 per cent calcium chloride for 15 minutes and found that during 25 days ambient storage at 15 to 16 °C flesh firmness in terms of pressure was found to be higher in the treated fruits as compared to control.

Drake and spayd (1983) reported that use of 3 per cent CaCl₂ in "Golden Delicious" apples resulted in retention of firmness in apples compared to control. The apples stored without treatment at 1°C for 5 months possessed firmness values of 12.0 compared to 13.0 lbs in case of CaCl₂ treated fruits stored at 1°C for same time. Poovaiah (1986) have also reported beneficial effects of calcium chloride treatment in firmness of apples during storage.

Guzewaska (1984) observed that apples dipped for one minute in 2 to 4 per cent calcium chloride were of higher quality after 6 to 7 months cold storage.

Apple texture is important in determining consumer acceptability. Several components affect this property, such as cell wall content and composition,

particle size and shape, moisture and lipid content (Maini *et al.*, 1985; Sams, 1999). However, softening is closely related to chemical changes in the pectin and middle lamellae (Kovacs *et al.*, 1999). It is also positively correlated with content of non-starch polysaccharides, and strongly correlated with the presence of galactose, glucose, arabinose, mannose and rhamnose in the hydrolysis of apple fibre (Gheyas *et al.*, 1998).

The “Golden Delicious” apples with initial firmness of 16.58 lbs were infiltrated with 3 to 4 per cent calcium chloride under vacuum (350 mm Hg) and stored for 3 months at 0°C and firmness of 13.27 lbs was retained by the fruits after storage (Poovaiah, 1986).

Maini *et al.* (1985) reported that the firmness of “Red Delicious” apples stored at 1°C at 85 to 90 per cent relative humidity for 135 days decreased from 5 to 3.2 kg during storage. The decrease infirmness has been attributed to breakdown of starch.

Fruit texture is related to cell wall structure and firmness loss during ripening is a consequence of enzymatic activity on cell wall constituents (Eskin, 1990). Cell walls of apple incorporated methyl groups into polygalacturonate from 14C-methionine during ripening (Knee, 1978). The mechanism of polymerization of the sugar nucleotides to complex cell wall polysaccharides is poorly understood, although the enzymes involved appear to be membrane bound (Eskin, 1990). Fruit softening is attributed to an increase in soluble pectic substances, with a concomitant decrease in insoluble pectins (protopectins) (Brady, 1987; Eskin, 1990).

Nazir (1992) reported that fruits “Red Delicious” apples treated with CaCl₂ (4%) for 5 minutes under 300 mm Hg pressure had better firmness 6.25 and 6.35 kgs/cm² under refrigerated and CA storage after 210 days than untreated fruits.

Mir *et al.* (1993) reported retention of better firmness in calcium chloride treated “Red Delicious” apples stored under ambient conditions during storage. There was decrease in firmness with the passage of storage period. However, the untreated apples were less firmer 10.82 lb compared to 12.20, 12.40, 13.16, 14.14 lb dipper in 1, 2, 3, and 4 per cent CaCl₂ solution for 5 minutes, respectively before storage.

Koksai *et al.* (1994) applied postharvest dip treatment of semperfresh solutions of various concentrations (0, 0.5, 1.0 and 1.5%) to the starkspur Golden Delicious apples and after treatment fruits were stored in 0±0.5°C and 85-90 per cent relative humidity for 120 days. Fruit firmness declined during the storage period and the apples possessed 16.8 lb flesh firmness values at the beginning of storage period. These values in control (C₁ and C₂) and the fruit applied with 0.5, 1.0 and 1.5 per cent semperfresh decreased to 11.3, 11.0, 10.71, 10.0 and 10.0 lb during storage, respectively.

El-Ansary *et al.* (1994) conducted two years storage study at 4°C, RH 90-92 per cent on Anna apple quality using preharvest or postharvest application of calcium chloride. The preharvest treatment comprised of spraying apple tree thrice (every three weeks beginning about 20 days after petal fall) with 0 and 0.5 per cent CaCl₂ and postharvest treatment of calcium chloride at 3 per cent (w/v) was applied by vacuum (vacuum 350 mbar/3 min) infiltration or by dipping for 3 minute.

Mahjan and Chopra (1995) reported that initial fruit firmness values of “Red Delicious” apple was 82.40 newtons. The flesh firmness after storage period of 210 days 0±1°C was lowered to lower values and was influenced by postharvest treatments. The control fruits possessed firmness of 32.75 newtons and those treated with DPA 1500 ppm had flesh firmness of 47.06 newtons. Fruits dipped in Frutox 6 per cent and Frutox 6 per cent + DPA 1500 ppm had fruit firmness value of 45.11 and 46.19 newtons, respectively.

According to Surmacka-Szczesniak (2002) texture is an indicator of structural and mechanical properties of food products and determines consumer's acceptability. Fruit firmness is one of the basic criteria of fruit texture estimation and in some countries a specific degree of firmness is included in primary parameters for marketing (Hoehn *et al.*, 2003). The fruit firmness depends on fruit density related with the quality and storage performance of apple fruit (Amarante *et al.*, 2000). However, the softening rate has also been reported to vary from cultivar to cultivar, depending on the presence and expression of genes which regulate the activity of hydrolytic enzymes (Ingle *et al.*, 2000; Konopacka and Plochanski, 2002; Johnston *et al.*, 2001).

In general, flesh firmness decreases with successive harvests, i.e. with advanced maturity. Moreover, a distinct decline in flesh firmness is found during postharvest ripening depending on cultivar, storage regime (temperature, relative humidity, atmosphere) and duration. It is known that an inverse relationship between fruit size and flesh firmness exists (Kingston, 1992). Smaller fruit are generally firmer than larger fruit and this might be due to having more cell wall material per unit volume (Johnston *et al.*, 2002). Apple softening is largely due to disruption of the cementing material between cells (middle-lamella) which leads to a loss of cell to cell contact (Kingston, 1992; Johnston *et al.*, 2002; Tromp, 2005). Softening, which occurs in almost all fruits during ripening is considered being an undesirable process in apples. Many reports describe firmness as a crucial factor for consumer acceptance of apple fruit (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Harker *et al.*, 2002). Hence, firmness is very important from a commercial viewpoint, because softening limits the postharvest life of fruits by enhancing physical damage during handling and increasing the fruit susceptibility to diseases (Brady, 1987). Therefore, flesh firmness is an indicator of maturity and also an important parameter for judging quality throughout the distribution chain (Tromp, 2005). Measurements of flesh firmness are easily done

by using a penetrometer which records the force needed to insert a probe of known head diameter to a defined depth into the peeled fruit flesh.

2.8.2 Colour

The most obvious signs of fruit maturation are changes in the skin color. Color changes start with chlorophyll degradation, exposing the yellow carotenoids (Kvale, 1967; Gorski and Creasy, 1977; Eskin, 1990).

Knee (1972) reported a continuous decrease in chlorophyll during apple maturation, with a sharp drop at the onset of the climacteric. Total carotenoids followed the reverse trend. In the group of anthocyanins, cyanidin-3-galactoside (idaein), cyanidin-3- arabinoside, and cyanidin-7-arabinoside have been identified in ripe apple skin (Van Buren, 1970).

In apples, anthocyanin synthesis prevails during the phase of intense cell division of the fruit and during fruit ripening. In the later phase, anthocyanin formation rate is different according to the stage of maturity and to the cultivar.

Chalmers *et al.* (1973) observed an accumulation of anthocyanins on detached mature 'Jonathan' apples, whereas the accumulation stopped on unripe detached fruits. Therefore they suggested investigating further on the rate of accumulation of anthocyanins as an indicator of maturity. Anthocyanin formation is absolutely light-dependent (Saure, 1990), but the degree of the light response is cultivar and maturity dependent (Chalmers *et al.*, 1973).

Colour changes are the most obvious signal for fruit ripening. During ripening apple fruit generally show a rapid loss of green colour, which results from the degradation of chlorophyll structures (Tromp, 2005; Wills *et al.*, 2007). The yellow to red colour of apple fruit, which is due to anthocyanins and carotenoids in the peel, becomes visible with chlorophyll decline (Kingston, 1992; Tromp, 2005; Wills *et al.*, 2007). However, synthesis of carotenoids and development of anthocyanins might also occur *de novo* during ripening (Knee, 1988). Since the degradation of chlorophyll is a good indicator of maturity,

background colour (BGC) is visually assessed by comparison with colour charts or objectively measured by using ‘chromameters’ (Tromp, 2005). The degree of red colour cannot be used as a good indicator of maturity, since colour development is influenced by many preharvest factors.

2.8.3 Rot incidence

Giurea *et al.* (1979) tested several chemicals, Topsin M [thiophanate-methyl] at 0.07%, Tecto 60 [thiabendazole] at 0.2% or Benlate [benomyl] at 0.1% in post-harvest dips gave the best results in reducing the occurrence of *P. expansum* on stored Jonathan, Golden Delicious and “Red Delicious” apples.

Jahangir *et al.* (1993) concluded that storage at 0° and 10°C was the most effective in controlling rotting of “Red Delicious” apples by *Penicillium expansum*, *Alternaria alternata* and *Rhizopus sp.* All 3 fungi caused severe rotting at 20° and appreciable rotting at 30°. At 40° lesions caused by *P. expansum* and *R. sp.* spread very slowly and no lesions were formed by *A. alternata*. Storage at such high temp., however, can reduce fruit quality.

2.9 Chemical changes

2.9.1 Total soluble solids

Drake and Spayd (1983) reported no significant change in soluble solid content of “Golden Delicious” apples treated with or without CaCl₂ and stored under cold storage conditions (1°C) for a period of 5 months than those stored under cold ambient conditions for the same period.

Maini *et al.* (1983) treated “Red Delicious” apples with 4 per cent calcium chloride for 15 minutes and held under ambient conditions upto 25 days. They reported that brix of juice did not show much variation.

Sams and Conway (1984) reported that “Golden Delicious” apples infiltrated after harvest with calcium chloride solutions up in control (13.70 °Brix) after 210 days of storage.

Baviskar *et al.* (1995) observed a rise in TSS and sugars in ber fruits till it reached a peak followed by a gradual decline irrespective of postharvest treatment and storage conditions. The rise and fall in TSS and sugars was delayed in wax treated (W-0-12, 6%) fruits, polythene and CFB packed fruits but was rapid in control fruits. The rise and subsequent fall in TSS and sugars was at a faster rate at room temperature (9.13-28.58 °C) and (26.75-73.75%) followed by cool chamber and cool store. The higher temperature and low humidity at room temperature enhanced ripening resulting in faster utilization of soluble solids and sugars.

With advanced maturity and during postharvest apple ripening fruit generally become sweeter and more acceptable. The increase in sweetness is mainly due to the conversion of starch to sugars. Sugars are primarily found in the cell vacuole (Kader, 2002) and are usually a major component of soluble solids in the cell sap (Wills *et al.*, 2007). Therefore, it is easier and generally accepted to measure the percentage of soluble solids (% Brix) by using a refractometer, rather than directly measuring the sugar content by chemical means (Kingston, 1992; Wills *et al.*, 2007).

Ali *et al.* (2011) examined chemical changes in apple pulp during storage. They reported that ascorbic acid content, pH and sugar acid ratio was decreased while TSS and titratable acidity was increased in 90 days of storage. Treatments and storage intervals significantly affected the physico-chemical properties of apples.

2.9.2 Titratable acidity

Maini *et al.* (1983) treated “Red Delicious” fruits with 4 per cent calcium chloride for 15 minutes and stored under ambient conditions (15-16 °C). Acidity did not show much variation when data recorded at five days interval upto 25 days.

Mahajan and Chopra (1995) reported that in fruits “Red Delicious” apples treated with DPA (1500 ppm), frutox (6%), DPA + frutox (1500 ppm + 6%),

Bavistin (500, 100 and 1500 ppm) and Rovral (100, 250 and 500 ppm) and thereafter packed in corrugated fibre board carton and stored in cold storage maintained at 0 ± 1 °C and 90-95 per cent relative humidity the TSS content which was fairly low initially, increased as the storage period advanced, reaching a peak at 150 days of storage and declined thereafter. Revoral 500 ppm treated fruits recorded highest average TSS content (14.35 °Brix) and the lower average. TSS content was in control (13.70 °Brix) after 210 days of storage.

Baviskar *et al.* (1995) observed a rise in TSS and sugars in ber fruits till it reached a peak followed by a gradual decline irrespective of postharvest treatment and storage conditions. The rise and fall in TSS and sugars was delayed in wax treated (W-0-12, 6%) fruits, polythene and CFB packed fruits but was rapid in control fruits. The rise and subsequent fall in TSS and sugars was at a faster rate at room temperature (9.13-28.58 °C) and (26.75-73.75% RH) followed by cool chamber and cool store. The higher temperature and low humidity at room temperature enhanced ripening resulting in faster utilization of soluble solids and sugars.

Rice starch and other emulsion treatments significantly arrested the progressive decrease in TSS content of guava after 4, 8 and 12 days. After 12 days of storage, the highest TSS was recorded at 6 per cent wax emulsion treatment (9.66 °Brix) and lowest value of TSS (7.863 °Brix) in control. The mean highest TSS value was recorded in 6 per cent rice starch without gum treatment (11.41 °Brix) and the lowest mean TSS value is control (10.58 °Brix) which was significantly lowest than all other treatments (Singh and Mohammad, 1997).

The predominant acid in apple fruit is malic acid. Organic acids generally decline during maturation and apple ripening. Since organic acids can be considered as a source of energy (Wills *et al.*, 2007), their gradual decline during ripening might be explained by their utilization during postharvest respiration (Kader, 2002). The degree of decline in organic acids is dependent on cultivar, preharvest environmental and cultural factors as well as on postharvest storage-

and handling conditions. Since acidity in interaction with sweetness mainly contributes to fruit flavour, it is considered to be an important quality factor. Acidity is usually determined by titration.

2.9.3 Sugars

Ranjit *et al.* (1992) reported that there was increase in reducing sugars in mango fruits treated with 2, 4, ST, calcium nitrate and malic hydrazide as compared to control.

Baviskar *et al.* (1995) concluded that there was no appreciable difference in TSS and sugar content in different varieties of apples under varying treatments. However, the control fruits had comparatively higher TSS and total sugars which might be attributed to higher moisture loss in control as compared to lots treated otherwise. The rise and fall in total sugars was delayed in wax treated polythene and CFB packed ber fruits compared to rapid increase in control fruits.

2.9.4 Pectin

The textural changes during fruit ripening are related to alteration in cell structure. These changes usually involve an increase in water soluble pectin, decrease in protopectin, and a loss of pectic natural sugar, such as arabinose and galactose, from one or more of the pectic fractions (Seymour *et al.*, 1990). The increase in water soluble pectin is attributed to enzymatic degradation involving polygalacturonase (PG), pectinmethylesterase (PME) or β -galactosidase (Muda *et al.*, 1995). In peaches, water soluble pectin increased whereas alkali soluble pectin fraction decreased during ripening (Shewfelt, 1965; Pressey *et al.*, 1971). In strawberry, the total amount of galacturonic acid in the separated pectin fraction also decreases with ripening (Inari and Takeuchi 1997). In mango fruits, some studies showed different changes in pectin fractions from different cultivars during ripening. According to Tandon and Kalra (1984) water soluble (high methoxyl) and ammonium oxalate soluble (low methoxyl) pectin fractions increased, while the alkali soluble (protopectin) fraction decreased, during

ripening of mango fruit (cv Dashehari). As the fruits ripened, they softened largely because of enzymatic deesterification and the depolymerization of cell-bound pectin, which yielded water and ammonium oxalate (pectinic acid) soluble pectin. Protopectin, upon hydrolysis, yields water soluble pectins (Mizuta and Subramanyam 1973). In addition, Mitcham and McDonald (1992) found that the ripening of 'Keitt' and 'Tommy Atkins' was associated with an increase in soluble pectin as well as a decline in arabinosyl, rhamnosyl, and galactosyl residues. Muda *et al.* (1995) confirmed that the chelator soluble pectin fraction is progressively depolymerized and becomes more polydisperse during ripening in 'Tommy Atkins'. However, in a study by Roe and Bruemmer (1981), softening in 'Keitt' mango was accompanied by a decline in the amount of both water and alkaline soluble pectin. In contrast, oxalate soluble pectin increased during ripening. The decline in alkaline soluble pectin was most closely correlated with the loss of firmness of the mango fruit. Roe and Bruemmer (1981) mentioned that the conversion of protopectin (alkali soluble) to water soluble pectin in peach was accompanied by polymer degradation but not to the extent to be observed in 'Keitt' mango. Degradation of mango pectin apparently proceeded to the stage that the product molecules were small enough to be soluble in ethanol, and were not precipitated in alcohol insoluble solid (AIS). Robertson and Swinburne (1981) also reported a significant inverse relationship between the firmness of unpeeled kiwifruit and water soluble pectin content.

2.9.5 Phenolics

Total phenolic content declines throughout fruit development, resulting in a decrease in bitterness and astringency (Clifford, 1997). Acceptable quality also depends on the fruit aroma, which is caused by a large number of volatile compounds including alcohols, aldehydes, carboxylic esters and ketones (Dixon and Hewett, 2000). Starch is transported from source organs, and accumulates in fruit during development. Its hydrolysis before fruit maturation is the main source of fruit sugars (sucrose, glucose, fructose, and minor contribution of sorbitol),

which are responsible for the sweetness (Knee, 1993). Organic acids (malic and citric acids) are other factors associated with fruit taste (Ferguson and Boyd, 2002). They are substrates of respiration and their levels decrease during ripening (Ackermann, 1992).

Henríquez *et al.* (2012) indicated that the total phenolic content, the antioxidant capacity, and the mineral composition, of peel were substantially higher than those of whole fruit, and pulp for all the apple cultivars studied. Among cultivars, “Red Delicious” apple peels have a significantly much higher content of total phenolic (11.6 mg gallic acid equivalents [GAE] g⁻¹ FW) and a higher FRAP (209.9 μmol Fe⁺² g⁻¹ FW). Additionally, a high correlation between total phenolic content and antioxidant capacity was found in all the cultivars and fruit tissues analyzed, except in the apple pulp.

2.9.6 Enzymes

Pectic enzymes are important factors in the texture of fruits and vegetables during ripening, postharvest storage, and processing (Pilnik and Rombouts, 1981, Voragen *et al.*, 1995). Pectic enzymes occur naturally in many fruits and vegetables (endogenous enzymes), but they are also added as processing aids (exogenous enzymes) (Benen *et al.*, 2003). Pectic enzymes are composed of main-chain depolymerases and esterases active (e.g. pectinmethylesterase) on methyl- and acetylesteresters of galacturonic acid residues in the galacturonan and rhamnogalacturonan structure. The depolymerizing enzymes comprise hydrolases (e.g. exo- and endo-polygalacturonase) as well as lyases (e.g. pectin lyase, pectate lyase) (Benen *et al.*, 2003). The points of attack of pectic enzymes are illustrated in. Pectin esterases act on methyl- and acetylesteresters of galacturonosyl uronic acid in the galacturonan and rhamnogalacturonan structure. Pectin lyase depolymerizes highly esterified pectin by splitting glycosidic linkages next to methyl esterified groups through a β-elimination mechanism. Pectate lyase also attacks glycosidic linkages next to a free carboxyl group. Another depolymerization pathway is by the combined action of pectinmethylesterase

(PME) and polygalacturonase (PG). In the presence of a water molecule, PME splits off methanol from highly esterified pectin, transforming it into low ester pectin, which is hydrolyzed by PG, attacking glycosidic linkages next to a free carboxyl group (Pilnik and Voragen 1989). Both classes of enzymes contain enzymes that act on the homogalacturonan backbone, or 'smooth' part, and enzymes that degrade the rhamnogalacturonan part, also known as 'hairy regions' (Benen *et al.*, 2003).

Teresa *et al.* (1992) observed the activity of polygalacturonase (EC 3.2.1.15) increased slightly during fruit softening, while galactosidase (EC 3.2.1.23) activity remained constant. Salt-extracted pectinesterase (EC 3.1.1.11) activity increased during ethylene treatment, then dropped rapidly to low levels as fruit softened. Residual pectinesterase activity, extracted after digestion of the cell wall pellet with a fungal enzyme mix, decreased on softening. The rapid softening of kiwifruit in response to ethylene treatment may be initiated by an induction of pectinesterase activity, causing increased de-esterification of cell wall pectins, followed by degradation of solubilized pectin.

Mahajan (1994) concluded that TSS, total sugars and soluble protein contents increased in "Red Delicious" apples during 150 days of storage at $0\pm 1^{\circ}\text{C}$ and then declined. Titratable acidity, total phenols and pectin contents declined linearly during 7 months of storage. Polygalacturonase and cellulase activities increased for 150 days of storage, leading to fruit softening. These activities then declined.

Gonzalez and Rosso (2011) determined PME activity in samples of pectinases by UV-VIS spectroscopy, to measure the acid and methanol produced in the reaction of pectin with pectinase and to verify the thermal inactivation of exogenous PME in mango juice. The reaction showed greater activity at pH 4.0 to 4.5 and at a temperature of 45°C . PME activity determined by UV-VIS spectroscopy with bromophenol blue indicator showed a good correlation with the activity determined by potentiometry and with alcohol oxidase. The results

showed that bromophenol blue indicators can be used to determine PME activity in samples of pectinases where the optimum pH is located in the acidic range. The thermal inactivation of exogenous PME in mango juice occurred at 75° C for 20 min of exposure.

2.10 Sensory quality of apple

Visser *et al.* (1968) showed a high correlation between perceived sweetness and % total sugars as measured with a hand refractometer, and between perceived acidity and pH of apple juice. The amount of acids affected the perceived sweetness intensity more than the sugars affected perceived acidity.

Although of practical use, soluble solids and titratable acidity don't give any indication of the quality of sugars and acids, and the effect on the palate of each of them is not equal. In solution, fructose tastes sweeter than sucrose, which tastes sweeter than glucose (Shallenberger and Birch, 1975). Malic acid, which is predominant in apples and pears, has a longer effect on the taste buds with less intensity than citric acid (Gardner, 1966).

Forty-five attributes were categorized in appearance, external and internal aroma, feel of apple in hand, taste, texture, and after-taste. This study helped understanding which are the important flavor criteria in apple and how they changed with storage. It also pinpointed the difficulties encountered with the fresh product where the variation within a fruit was as great as the variation between fruits (Williams and Carter, 1977).

Watada *et al.* (1980) chose 15 attributes to describe eating quality of apples: hardness, crispiness, toughness, mealiness, sponginess, juiciness, sweetness, acidity, astringency, starchiness, spiciness, vegetativeness, mustiness, cardboardy flavor, and fruitiness. The intensity of the attributes were plotted on a circular graph and differences of patterns between varieties, or due to duration of storage, were observed. Instrumental measurements have been extensively correlated with sensory attributes. Sweetness and acidity are the most important

taste attributes in fruit (Bidabe *et al.*, 1969; Thiault, 1975; Visser *et al.*, 1968; Vangdal, 1985).

Taste and aroma contribute largely to apple overall quality, texture has been considered even more significant (Ananthakrishna *et al.*, 1983; Mast and Faldheim, 1983; Wills *et al.*, 1980). The Ottawa Texture Measuring System (OTMS) is an instrument that gives a measure of texture and juiciness by compressing a slice of apple, and the Magness Taylor pressure tester gives the resistance of the fruit flesh at one point. OTMS values were better correlated to overall quality (sensory) than titratable acidity, refractive index and Magness Taylor values. Therefore, OTMS has been recommended for use as an index for apple quality (Ananthakrishna *et al.*, 1983). The Magness Taylor penetrometer does not give any indication on texture but is still widely used to measure apple firmness (Watada and Abbott, 1985).

Vangdal (1985) reported that there was a better correlation between flavor and the soluble solids:acidity ratio than flavor and each of those components alone. The index $SSC + 10(TA)$ established by Thiault (1975) for “Red Delicious” has been widely used in Europe as a quality index.

Once the physiological and pathological disorders have been controlled by appropriate horticultural and storage practices, the eating quality is the final goal of getting horticultural crops to the consumer (Knee and Smith, 1989). Among available tools for the researcher to contribute to the better understanding of quality are descriptive analyses where a panel of trained people describes the product's sensory attributes, which can be compared with instrumental measurements, and acceptance tests (Stone and Sidel, 1985). Acceptance tests usually precede large scale consumer market research. The five-point hedonic scale and paired comparison tests are the most commonly used techniques (Stone and Sidel, 1985).

Prakash *et al.* (1985) picked apples at 3 stages of maturity during the peak harvest period, for 3 consecutive seasons (1500 apples/season). The best time to harvest was when 70% of apples were mature (or slightly under- or over-mature). Fruits harvested at this time showed longer, shrivel-free cold storage life and maintained their superior organoleptic properties throughout storage.

Zerbini *et al.* (1999) harvested apples four times at weekly intervals from 4-year-old trees in an experimental orchard in NE Italy. Selected and trained panellists evaluated the intensity of sensory characteristics of fruits after storage (4 months at 0°C in air) and shelf-life at 20°C. Harvest time mainly influenced fruit texture after storage: in Staymared the juiciest and the most crisp fruits were those of the intermediate harvests, in Red Chief those of the first harvest, while in Fuji those of the last two harvests. Sensory quality of Braeburn and Golden Delicious was not affected by harvest time.

Chapter – 3

MATERIAL AND METHODS

Investigations connected with the studies on “Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. “Red Delicious” were carried out in the Division of Post-Harvest Technology, Sher-e-Kashmir University of Agriculture Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu & Kashmir during the two consecutive years viz., 2011 and 2012. The details of the techniques followed and material used during the course of investigations are described as below :

3.1 Material

Apple cv. “Red Delicious” of uniform shape, size and firm texture was procured from the apple orchard of Mr. Mohd Afzal Ganai, Pulwama Kashmir about 40 kilometers from Srinagar. Apple fruits were harvested at three different dates with an interval of seven days at around 6.00 pm. After harvest, these were manually sorted by discarding deformed, bruised, punctured and stemless fruits. One lot of fruits was separated and kept under shade for 12 hours for cooling which served as control T₁ (shade-cooling). The remaining fruits were pre-cooled by spraying cold tap water for 10 minutes with occasional turning T₂ (hydrocooling). Next day hydrocooled fruits were divided into two more lots, one lot was sprayed with 3 per cent calcium chloride which served as T₃ (hydrocooling + CaCl₂). Then these fruits were packed in plastic crates and brought to laboratory. Next day a portion from both hydrocooled fruits (T₂) and (hydrocooled + CaCl₂) T₃ were waxed by 6 per cent paraffin wax which served as T₄ (hydrocooling + 6% paraffin wax) and T₅ (hydrocooling + 3% CaCl₂ + 6% paraffin wax), respectively.

3.2 Calcium chloride and wax treatment

The shade-cooled fruits were designated as T₁ (control) and hydro-cooled fruits were named as T₂. Remaining pre-cooled fruits were given three different



Plate-1 : Waxing process of Apple (*Malus domestica* Borkh.) cv. “Red Delicious”

treatments. One lot was sprayed with 3 per cent calcium chloride and designated as T₃. Second was waxed by wax machine and designated as T₄. Third lot of pre-cooled fruits were sprayed with calcium chloride and waxed and designated as T₅. All the treated fruits were stored under ambient and refrigerated conditions for storage studies.

3.3 Storage

After treatment, samples were kept separately under two storage conditions viz., ambient (Temperature 18±2°C, RH 75±5 %) and refrigerated (Temperature 2±1°C, RH 85±5 %) storage for monitoring quality changes during storage periods. Fruits were evaluated for each parameter after every 20 days (0, 20, 40, 60, 80 and 100 days) in case of both storage conditions with three replications.

3.4 Post-storage shelf life studies

Samples of all treatments were taken out from cold stores (2±1°C, RH 85±5 %) after 20 days of storage interval and kept at ambient temperature (18±2°C, RH 75±5%) for some time and were evaluated for each parameter.

After different treatments, various physico-chemical and organoleptic changes were evaluated during storage.

3.4.1 Physical properties

3.4.1.1 Fruit length (mm)

The length of ten randomly selected fruits from each treatment in each replication was measured with the help of vernier's calliper's, averaged and expressed in millimetres (mm).

3.4.1.2 Fruit diameter (mm)

The diameter of ten randomly selected fruits from each treatment in each replication was measured with the help of vernier's calliper's, averaged and expressed in millimetre (mm).



Ambient storage



Refrigerated storage

Plate-2 : *Apple (Malus domestica Borkh.)* cv. “Red Delicious” under ambient and refrigerated storage



Ambient storage



Refrigerated storage



Ambient storage



Refrigerated storage



Ambient storage



Refrigerated storage

Plate-3 : Fruits after ambient and refrigerated storage of 200 days

3.4.1.3 L/D ratio

L/D ratio of ten randomly selected fruits was calculated by dividing the length of fruits with that of diameter and the shape of fruit was determined.

3.4.1.4 Average fruit weight (g)

The representative sample of 30 fruits in replicates were taken and weighed on electronic balance (Metzer Biomedical and Electronics Pvt. Ltd) to calculate average fruit weight in grams.

3.4.1.5 Firmness (lb/inch²)

Fruit flesh firmness (lb/inch²) data pertaining to fruit flesh firmness was recorded with the help of penetrometer (Effigi, 11 mm Prob.) for five fruits per treatment (Pocharski *et al.*, 2000).

3.4.1.6 Colour assessment (L*, a*, b*)

Fruit surface colour was determined with a chromometer (Model CR-2000, Minolta, Osaka, Japan), equipped with a 8-mm measuring head and a c illumination (6774 K). The meter was calibrated using the manufacturer's standard white plate. Colour changes were quantified in the L*, a*, b* colour space. L* refers to lightness of the colour of the sample fruit and ranges from black = 0 to white = 100. A negative value of a* indicates a green colour where the positive value indicates red-purple colour. A positive value of b* indicates a yellow colour and the negative value a blue colour.

3.4.1.7 Rot incidence (%)

Per cent soft rot in each replication of treatments was examined visually and counted during 150 days storage and their disease percentage of fruits was calculated by formula as under :

$$\text{Rot incidence (\%)} = \frac{\text{Number of diseased fruits}}{\text{Total number of fruits}} \times 100$$

3.4.1.8 Physiological loss in weight (PLW)

For determining the PLW from each treatment 10 fruits were taken separately. The original weight of these fruits was recorded soon after precooling treatment. The fruits were subsequently weighted at each stage of analysis. The PLW was expressed on percentage basis as per equation 3.4

$$\text{PLW (\%)} = \frac{\text{Original weight} - \text{subsequent weight at analysis}}{\text{Original weight}} \times 100$$

3.4.2 Chemical properties

3.4.2.1 Moisture content (%)

Moisture content in sample was determined by hot air oven method (A.O.A.C, 1995). 5 g of sample was dried at 60-70°C for 6-8 hours to constant weight under a vacuum of 750 mm Hg. The loss in weight was determined to calculate the moisture content.

$$\text{Moisture (\%)} = \frac{\text{Initial weight of sample} - \text{Weight of sample after drying}}{\text{Initial weight of sample}} \times 100$$

3.4.2.2 Total soluble solids (°Brix)

Total soluble contents were determined by a hand refractometer (model Atago N, Japan) having range of 0-32 per cent and the values obtained in per cent were corrected at 20°C. The fruits for the test were divided into 3 replicates each consisting of 5 fruits and were subjected to juice extraction using an Omni juice extractor, followed by filtration through muslin cloth. Two to three drops of the filtered juice were put on the refractometer lens for TSS measurement and expressed as °Brix.

3.4.2.3 Titrable acidity (%)

Titration acidity was determined by taking a known weight of fruit juice and making a known volume of it by adding distilled water. Then a known volume of this liquid was treated against 0.1 N sodium hydroxide using phenolphthalin as an indicator. Titrable acidity was expressed as percentage malic acid as per equation.

$$\text{Titrable acidity} = \frac{\text{Titre} \times \text{Normality of alkali} \times \text{Vol. make up} \times \text{Equivalent weight of acid}}{\text{Vol. of sample taken for estimation} \times \text{Weight or volume of sample taken} \times 1000} \times 100$$

3.4.2.4 Total sugars (%)

Total and reducing sugars were estimated by Lane and Eynon method (1923). 5 g of sample was blended with 100 ml distilled water, boiled for 1 hour in 150 ml beaker. Loss of water during boiling was made up by addition of distilled water. The solution was heated, transferred to a 250 ml volumetric flask and neutralized using sodium hydroxide. To it 2 ml of 45 per cent lead acetate was added, shaken well and left undisturbed for 10 minutes. Then it was de leaded with 2 ml of potassium oxalate and volume made up to 250 ml. The solution was filtered and marked as solution (1).

For estimation of total sugars, 50 ml of solution (1) was inverted in 200 ml of flask by adding 5 g of citric acid to it and then boiled for 15 to 20 minutes and cooled, neutralized with 1N sodium hydroxide till pink colour appeared using phenolphthalein indicator volume was made upto 250 ml and solution designated as solution II. 5 ml of each Fehlings solution (A) and (B) were taken in a titration flask containing 25 ml of distilled water titrated against solution (II) for estimation of total sugars, till red colour was observed. After this 2 drops of methylene blue (indicator) were added and titration was continued till brick red precipitate was observed. During the entire period, the flask was kept on burner to keep the contents hot. Percentage total sugars were calculated using the followed equation

$$\text{Total sugars (\%)} = \frac{0.05 \times \text{volume made}}{\text{Titrate volume} \times \text{weight of sample}} \times 100$$

3.4.2.5 Per cent juice content

Per cent juice content Juice was extracted from five randomly selected fruit from each treatment with the help of juice extracting machine, weighed and the percentage was computed as described by Rehman *et al.* (1982).

$$\text{Per cent juice} = \frac{\text{Weight of juice fruit}^{-1}}{\text{Average weight of fruit}} \times 100$$

3.4.2.6 Calcium (%)

Calcium content of samples was determined by atomic absorption spectrophotometer (AAS). Calcium was determined by digesting the sample obtained by dry ashing. Samples were digested with HNO₃ and HClO₄. Digested sample were diluted to 100ml with distilled water. Standards were prepared by 0 to 15 mg Calcium per litre solution. Reading was taken with AAS using an acetylene-air flame (A.O.A.C, 1995).

3.4.2.7 Pectin content (%)

Pectin was precipitated as calcium pectate in fresh fruit samples. 5 g of sample was boiled with 400 ml of 0.05N HCl for 6 minutes, cooled and volume made upto 100 ml with distilled water. The solution was filtered through Whatman No.4 filter paper. To 100 ml of filtrate, 250 ml of distilled water was added and then neutralised with 1N NaOH. The solution was kept undisturbed for 24 hrs, followed by addition of 50ml of 1N acetic acid and 25 ml of 1N CaCl₂ were added to the solution. The solution was left undisturbed for 1 hour, boiled for 1 or 2 minutes and filtered through previously weighed filter paper. The precipitate on filter paper was washed with boiling water until free from chlorides and the filter paper containing precipitate was dried for 24 hrs at 60°C, cooled in a dessicator next day and weighed. The pectin as per cent calcium pectate was determined using the following equation :

$$\text{Calcium pectate (\%)} = \frac{\text{Weight of calcium pectate} \times 500}{\text{ml of filtrate taken} \times \text{weight of sample}} \times 100$$

3.4.2.8 Anthocyanin content

The anthocyanin content was estimated by blending a known weight of fruit with a known volume of ethanolic HCl (95% ethanol : 1.5 N HCl) in a blender and stored overnight under refrigeration at 4°C. The mixture was filtered and residue was washed repeatedly till a known volume was obtained. A small

aliquot was diluted with ethanolic HCl to yield optical density (OD) checked at 530 nm measurements within the optical range of spectrophotometer.

3.4.2.9 Ascorbic acid content (mg/100 g)

Ascorbic acid was determined by the standard method as reported in AOAC (1990). Dye solution for Ascorbic acid determination: Fifty mg of 2, 6 dichlorophenol indophenols dye and 42 mg of sodium bicarbonate was weighed, dissolved in hot distilled water and volume was made up to 250 ml. Fifty mg of standard ascorbic acid was taken in 50ml volumetric flask and the volume was made up 0.4 per cent oxalic acid. This standard ascorbic acid was titrated against dye. Titration of the sample Ten ml of sample was taken in 100 ml volumetric flask and volume was made by adding 0.4 per cent oxalic acid .Then 10 ml of prepared sample was taken in the flask and was titrated against dye until light pink colour appeared, which persisted for 15 seconds. Three consecutive readings were taken for each sample. The ascorbic acid was calculated by using the following formula;

$$\text{Ascorbic acid} = \frac{F \times T \times 10}{D \times S} \times 100$$

F = Factor from standardisation = (ml of Ascorbic acid)/ml of dye

T = ml of dye used for sample

S = ml of diluted sample taken for titration

D = ml of sample taken for dilution

3.4.2.10 Polyphenols (mg/100 g)

Polyphenol content of fruit was estimated through a procedure developed by Elizabeth and Kelly (2007). Five gram of sample was boiled for 30 minutes in 400ml distilled water, diluted to mark with distilled water in a 500ml volumetric flask and filtered. In order to estimate the phenolic content, 0.1 ml of filtrate was taken in a test tube and after adding 0.2 ml of 10 per cent Folin-ciocalteau reagent, the mixture was vortexed thoroughly. After vortexing 0.8 ml of sodium carbonate

was added in to each tube and was incubated at room temperature. After incubation absorbance was measured at 765 nm and poly phenolic content was calculated using standard curve of gallic acid through following equation:

$$\text{Polyphenolic content (mg/100 g)} = \frac{\text{mg of Gallic acid from standard curve} \times \text{dilution}}{\text{ml of sample taken for colour development} \times \text{Weight of solids in sample}} \times 100$$

3.4.2.12 Pectin methyl esterase (Methnol eq. $\mu\text{mol/litre/day}$)

PME activity in apple juice was determined after the activity was extracted from the particulate fraction with high salt. A 16000 g pellet was prepared from a sample of unfiltered Red Delicious apple juice. This pellet was washed twine with 5.0 mM acetate buffer (pH 1.5) and then resuspended in 0.5 M NaCl and 0.1 M-NaOH (pH 7.5) and the 16000 g supernatant collected. This supernatant was assayed for PME activity essentially as described for the purified PME except of 0.2 mL aliquot of the supernatant was used in a final assay volume of 1.0 mL and NaOH (pH 7.5) was used as the buffer (Gordon and Diane, 2004).

After incubation of the samples for 10 min at 30 °C, 200 μL of 5 mg/mL Purpald in 0.5 N NaOH was added, and the samples were vigorously vortexed to ensure oxygenation. After an additional 30 min at 30°C the samples were removed from the water bath and 0.6 mL of H_2O was added for a final volume of 1.0 mL. absorbance at 550 nm was then determined.

3.4.2.12 Polygalactouronase activity (% loss in viscosity)

The polygalcturonase activity (PG) was determined by the method described by Mahadevan and Sridhar (1982) where the enzyme action mixture consisted of enzyme extract (2 ml) prepared by crushing fruit flesh, 4 ml of sodium polypectate substrate (dissolving 750 mg of the sodium polypectate in 100 ml of acetate buffer, pH 5.2, heated to 50-60 °C and placed in a blender for mixing), and 1 ml of acetate buffer. Using Ostwald- type viscometer the content was mixed by drawing air gently through the large arm of the viscometer and

suction was applied through the small arm, and the initial efflux time of mixture was determined. After 16 hours the efflux time of the mixture was measured again

3.4.3 Sensory evaluation

Sensory quality attributes such as colour, texture, flavour and overall acceptability of apple samples were evaluated by semi-trained panel of 10 members drawn from scholars and staff members of Division of Post Harvest Technology, SKUAST-Kashmir, Shalimar (Ranganna, 1986). The panellist were provided with coded samples of apple and were requested to note their sensory responses on the basis of colour, texture, flavour and overall acceptability on 5-pont hedonic scale as under :

5	:	Excellent
4	:	Very Good
3	:	Good
2	:	Fair
1	:	Poor

3.5 Economic feasibility estimates

The product formulation involves 2 types of cost, one is fixed cost and the other is variable cost. Fixed costs are those which are run over many years and only a part of the services of these assets were utilized in a single production period. While as variable costs are those which get transformed into the ultimate production during particular season. Thus in our situation fixed costs are related to machinery and equipments while as variable cost involves expenses on chemicals, raw materials, packaging materials etc. Estimated by cost/benefit ratio.

3.6 Statistical analysis

The data was statistically analysed through R-Software using Completely Randomized Design (CRD) in factorial experiment (Gomez and Gomez, 1984).

Chapter – 4

EXPERIMENTAL FINDINGS

4.1 Physical properties

4.1.1 Fruit Length (mm)

Data pertaining to effect of harvest dates, postharvest treatments and storage periods on length of “Red Delicious” apple under ambient conditions is presented in Table 1. A mean maximum length of 74.21 mm was observed in H₂ and minimum of 72.32 mm in H₁ at 0 days of storage.

Postharvest treatments showed a significant effect on length. Highest length of 68.12, 70.36 and 69.77 mm was observed for T₅ while as T₁ recorded the lowest mean length of 67.85, 69.88 and 69.20 mm in three harvest dates H₁, H₂ and H₃ respectively.

There was significant decrease in length during storage of 100 days under ambient conditions. Mean value of length decreased from 73.55 mm at 0 days to 62.26 mm after 100 days of storage.

Effect of harvest dates, postharvest treatments and storage periods on length of “Red Delicious” apple under refrigerated conditions was studied and is presented in Table 1. A mean maximum length of 74.21 mm was observed in H₂ and minimum of 72.32 mm in H₁ at 0 days of storage.

Under refrigerated conditions highest length of 71.24, 72.74 and 72.72 mm was observed for T₅ while as T₁ recorded the lowest mean length of 70.80, 72.19 and 72.00 mm in three harvest dates H₁, H₂ and H₃, respectively. Postharvest treatments showed a significant effect on length.

Mean value of length decreased significantly from 73.55 mm at 0 days to 69.88 mm after 100 days of storage under refrigerated conditions.

Table-1 : Effect of harvest dates, post harvest treatments and storage conditions on fruit length (mm) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	72.32	71.82	70.72	67.82	63.82	60.52	67.85	72.32	71.92	71.32	70.72	69.82	68.72	70.80
	T ₂	72.32	71.92	70.82	67.92	63.92	60.62	67.92	72.32	72.02	71.62	70.92	69.92	68.92	70.95
	T ₃	72.32	72.02	71.02	68.02	64.12	60.82	68.05	72.32	72.22	71.82	71.12	70.12	69.22	71.14
	T ₄	72.32	71.92	70.92	67.92	64.02	60.72	67.97	72.32	72.12	71.72	71.02	70.02	69.02	71.04
	T ₅	72.32	72.02	71.02	68.12	64.32	60.92	68.12	72.32	72.32	71.92	71.22	70.32	69.32	71.24
	Sub Mean	72.32	71.94	70.90	67.96	64.06	60.72	67.98	72.32	72.12	71.68	71.00	70.04	69.04	71.03
H ₂	T ₁	74.21	72.81	71.51	70.21	67.31	63.21	69.88	74.21	73.51	72.71	72.11	71.11	70.31	72.19
	T ₂	74.21	72.81	71.51	70.31	67.41	63.41	69.94	74.21	73.51	72.71	72.11	70.31	70.31	72.43
	T ₃	74.21	72.91	71.71	70.51	67.71	63.71	70.13	74.21	73.71	72.91	72.31	71.71	70.91	72.63
	T ₄	74.21	72.91	71.61	70.51	67.51	63.51	70.04	74.21	73.61	72.81	72.21	71.41	70.71	72.49
	T ₅	74.21	74.01	71.81	70.71	67.71	63.71	70.36	74.21	73.71	73.11	72.31	71.91	71.21	72.74
	Sub Mean	74.21	73.09	71.63	70.45	67.53	63.51	70.07	74.21	73.61	72.85	72.21	71.29	70.69	72.48
H ₃	T ₁	74.12	72.72	71.52	69.22	66.62	62.32	69.20	74.12	73.42	72.52	71.72	70.82	69.72	72.00
	T ₂	74.12	72.72	71.62	69.42	66.42	62.42	69.45	74.12	73.42	72.52	71.72	70.82	69.82	72.07
	T ₃	74.12	72.92	71.72	70.02	66.62	62.62	69.67	74.12	73.62	72.72	72.02	71.02	69.92	72.24
	T ₄	74.12	72.82	71.62	69.12	66.52	62.52	69.45	74.12	73.52	72.62	71.92	70.92	69.92	72.17
	T ₅	74.12	72.92	71.82	70.12	66.82	62.82	69.77	74.12	73.62	72.72	72.02	71.02	70.12	72.72
	Sub Mean	74.12	72.82	71.66	69.58	66.60	62.54	69.55	74.12	73.52	72.62	71.88	70.92	69.90	72.16
Grand Mean	73.55	72.62	71.40	69.33	66.06	62.26	69.20	73.55	73.08	72.38	71.70	70.75	69.88	71.89	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			=	0.001			Harvest (H)			=	0.006		
		Treatment (T)			=	0.002			Treatment (T)			=	0.001		
		H x T			=	0.012			H x T			=	0.021		
		Storage (S)			=	0.019			Storage (S)			=	0.023		
		H x S			=	0.025			H x S			=	0.024		
		H x S x T			=	0.030			H x S x T			=	0.029		

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

4.1.2 Fruit Diameter (mm)

“Red Delicious” apples were stored under ambient conditions and data pertaining to effect of harvest dates, postharvest treatments and storage periods on diameter is presented in Table 2. A mean maximum diameter of 67.35 mm was observed in H₂ and minimum of 66.57 mm in H₁ at 0 days of storage.

Diameter varied significantly in different postharvest treatments. Highest length of 61.81, 62.13 and 62.07 mm was observed for T₅ while as T₁ recorded the lowest mean diameter of 60.14, 61.03 and 61.00 mm in three harvest dates H₁, H₂ and H₃, respectively.

Under ambient conditions, there was significant decrease in diameter during storage of 100 days. Mean value of diameter decreased from 67.05 mm at 0 days to 52.68 mm after 100 days of storage.

Data pertaining to effect of harvest dates, postharvest treatments and storage periods on diameter of “Red Delicious” apple under refrigerated conditions is presented in Table 2. A mean maximum diameter of 67.35 mm was observed in H₂ and minimum of 66.57 mm in H₁ at 0 days of storage.

Postharvest treatments showed a significant effect on diameter. Highest diameter of 65.15, 65.32 and 65.70 mm was observed for T₅ while as T₁ recorded the lowest mean diameter of 64.27, 64.98 and 65.00 mm in three harvest dates H₁, H₂ and H₃, respectively.

Mean value of length decreased significant from 67.05 mm at 0 days to 62.77 mm after 100 days of storage under ambient conditions.

4.1.3 L/D ratio

Data pertaining to effect of harvest dates, postharvest treatments and storage periods on L/D ratio of “Red Delicious” apple under ambient conditions is presented in Table 3. A mean maximum L/D ratio of 1.08 was observed in H₃ and minimum of 1.06 in H₁ at 0 days of storage.

Table-2 : Effect of harvest dates, post harvest treatments and storage conditions on fruit diameter (mm) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	66.57	65.67	63.57	59.67	56.17	52.17	60.14	66.57	65.77	64.57	63.67	62.77	62.27	64.27
	T ₂	66.57	65.67	63.67	59.67	56.27	52.27	60.69	66.57	65.87	64.77	63.77	62.97	62.27	64.37
	T ₃	66.57	65.87	63.87	59.87	56.37	52.37	60.82	66.57	66.07	64.97	64.17	63.47	62.37	64.85
	T ₄	66.57	65.77	63.77	59.77	56.27	52.27	60.74	66.57	65.87	64.87	63.97	63.07	62.37	64.45
	T ₅	66.57	66.07	64.07	59.97	56.70	52.57	60.18	66.57	66.17	64.97	64.22	63.70	62.47	65.15
	Sub Mean	66.57	65.81	63.79	59.79	56.31	52.33	60.77	66.57	65.95	64.83	63.96	63.05	62.35	64.45
H ₂	T ₁	67.35	65.35	64.45	60.35	56.67	53.15	61.03	67.35	66.35	65.15	64.35	63.65	63.05	64.98
	T ₂	67.35	65.75	64.55	60.55	56.95	53.15	61.38	67.35	66.55	65.25	64.55	63.75	63.15	65.10
	T ₃	67.35	66.35	64.75	60.65	57.15	53.35	61.60	67.35	66.75	65.35	64.65	63.85	63.25	65.20
	T ₄	67.35	66.05	64.75	60.55	57.05	53.15	61.48	67.35	66.65	65.25	64.55	63.75	63.15	65.12
	T ₅	67.35	66.45	64.85	60.75	57.50	53.35	61.13	67.35	66.85	65.55	64.85	63.95	63.35	65.32
	Sub Mean	67.35	65.97	64.67	60.57	57.05	53.23	61.47	67.35	66.63	65.31	64.59	63.79	63.19	65.14
H ₃	T ₁	67.24	66.24	64.24	60.24	56.34	52.24	61.00	67.24	66.54	65.34	64.64	63.84	62.44	65.00
	T ₂	67.24	66.44	64.34	60.44	56.34	52.44	61.21	67.24	66.64	65.54	64.94	63.94	62.64	65.16
	T ₃	67.24	66.54	64.44	60.64	56.54	52.54	61.32	67.24	66.74	65.94	65.04	64.14	62.94	65.34
	T ₄	67.24	66.44	64.44	60.54	56.44	52.44	61.26	67.24	66.64	65.74	65.04	63.84	62.94	65.24
	T ₅	67.24	66.74	64.84	60.94	56.94	52.74	62.07	67.24	66.74	66.14	65.24	63.34	62.94	65.70
	Sub Mean	67.24	66.48	64.42	60.52	56.48	52.48	61.27	67.24	66.66	65.74	65.04	63.82	62.78	65.21
Grand Mean		67.05	66.09	64.29	60.29	56.61	52.68	61.17	67.05	66.41	65.29	64.53	63.55	62.77	64.94
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.002				Harvest (H) =			0.002			
		Treatment (T) =			0.005				Treatment (T) =			0.001			
		H x T =			0.003				H x T =			0.005			
		Storage (S) =			0.013				Storage (S) =			0.014			
		H x S =			0.015				H x S =			0.012			
		H x S x T =			0.004				H x S x T =			0.006			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-3 : Effect of harvest dates, post harvest treatments and storage conditions on L/D ratio of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	1.06	1.07	1.09	1.09	1.11	1.13	1.09	1.06	1.07	1.08	1.09	1.09	1.08	1.08
	T ₂	1.06	1.07	1.09	1.11	1.11	1.13	1.10	1.06	1.07	1.08	1.09	1.09	1.08	1.08
	T ₃	1.06	1.07	1.09	1.11	1.11	1.13	1.10	1.06	1.07	1.08	1.09	1.09	1.09	1.08
	T ₄	1.06	1.07	1.09	1.11	1.11	1.13	1.10	1.06	1.07	1.08	1.09	1.09	1.08	1.08
	T ₅	1.06	1.07	1.09	1.11	1.11	1.13	1.10	1.06	1.07	1.08	1.09	1.09	1.09	1.08
	Sub Mean	1.06	1.07	1.09	1.11	1.11	1.13	1.09	1.06	1.07	1.08	1.09	1.09	1.08	1.08
H ₂	T ₁	1.07	1.08	1.08	1.13	1.14	1.15	1.11	1.07	1.08	1.09	1.09	1.09	1.09	1.09
	T ₂	1.07	1.08	1.08	1.13	1.14	1.15	1.11	1.07	1.08	1.08	1.09	1.09	1.09	1.08
	T ₃	1.07	1.07	1.08	1.13	1.15	1.15	1.11	1.07	1.08	1.09	1.09	1.09	1.09	1.09
	T ₄	1.07	1.07	1.08	1.13	1.14	1.15	1.11	1.07	1.08	1.09	1.09	1.09	1.09	1.09
	T ₅	1.07	1.08	1.08	1.13	1.15	1.17	1.11	1.07	1.07	1.09	1.08	1.09	1.09	1.08
	Sub Mean	1.07	1.08	1.08	1.13	1.14	1.15	1.11	1.07	1.08	1.09	1.09	1.09	1.09	1.08
H ₃	T ₁	1.08	1.08	1.09	1.13	1.15	1.16	1.12	1.08	1.08	1.09	1.08	1.09	1.09	1.09
	T ₂	1.08	1.08	1.09	1.13	1.15	1.15	1.11	1.08	1.08	1.09	1.08	1.09	1.09	1.09
	T ₃	1.08	1.08	1.09	1.13	1.15	1.16	1.12	1.08	1.08	1.08	1.09	1.09	1.09	1.09
	T ₄	1.08	1.08	1.09	1.13	1.15	1.16	1.12	1.08	1.08	1.09	1.09	1.09	1.09	1.09
	T ₅	1.08	1.07	1.09	1.14	1.15	1.16	1.12	1.08	1.08	1.08	1.08	1.08	1.09	1.08
	Sub Mean	1.08	1.08	1.09	1.13	1.15	1.16	1.11	1.08	1.08	1.09	1.08	1.09	1.09	1.08
Grand Mean	1.07	1.07	1.09	1.12	1.13	1.15	1.11	1.07	1.08	1.08	1.09	1.09	1.09	1.08	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			= NS				Harvest (H)			= NS			
		Treatment (T)			= NS				Treatment (T)			= NS			
		H x T			= NS				H x T			= NS			
		Storage (S)			= NS				Storage (S)			= NS			
		H x S			= NS				H x S			= NS			
		H x S x T			= NS				H x S x T			= NS			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Postharvest treatments showed a significant effect on L/D ratio. Highest L/D ratio of 1.10, 1.11 and 1.12 was observed for T₅ while as T₁ recorded the lowest mean L/D ratio of 1.09, 1.11 and 1.12 in three harvest dates H₁, H₂ and H₃ respectively.

There was significant decrease in L/D ratio during storage of 100 days under ambient conditions. Mean value of L/D ratio decreased from 1.07 at 0 days to 1.15 after 100 days of storage.

Table 3 gives data pertaining to effect of harvest dates, postharvest treatments and storage periods on L/D ratio of “Red Delicious” apple under refrigerated conditions. A mean maximum L/D ratio of 1.08 was observed in H₃ and minimum of 1.06 in H₁ at 0 days of storage.

T₅ recorded highest L/D ratio of 1.08, 1.08 and 1.08 was observed for while as T₁ recorded the lowest mean L/D ratio of 1.08, 1.09 and 1.09 in three harvest dates H₁, H₂ and H₃ respectively and postharvest treatments showed a significant effect on L/D ratio.

There was significant decrease in L/D ratio during storage of 100 days under refrigerated conditions. Mean value of L/D ratio decreased from 1.07 at 0 days to 1.09 after 100 days of storage.

4.1.4 Fruit weight (g)

“Red Delicious” apples stored under ambient conditions were evaluated and effect of harvest dates, postharvest treatments and storage periods was studied (Table 4). A mean maximum fruit weight of 166.40 g was observed in H₃ and minimum of 164.40 g in H₁ at 0 days of storage.

Postharvest treatments showed a significant effect on Fruit weight. Highest fruit weight of 159.00, 160.03 and 159.40 g was observed for T₅ while as T₁ recorded the lowest mean fruit weight of 157.83, 159.45 and 159.10 g in three harvest dates H₁, H₂ and H₃, respectively.

Table-4 : Effect of harvest dates, post harvest treatments and storage conditions on fruit weight (g) ratio of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	164.40	163.40	161.40	158.00	152.40	147.40	157.83	164.40	164.10	163.40	163.00	161.40	159.60	162.65
	T ₂	164.40	163.50	161.60	158.10	152.80	147.60	158.00	164.40	164.10	163.50	163.10	161.60	159.70	162.73
	T ₃	164.40	163.60	161.90	158.80	152.70	147.90	158.70	164.40	164.20	163.80	163.40	161.80	159.90	162.92
	T ₄	164.40	163.60	161.80	158.20	152.60	147.80	158.07	164.40	164.20	163.60	163.20	161.70	159.80	162.82
	T ₅	164.40	163.90	161.90	158.30	153.80	147.90	159.00	164.40	164.30	163.80	163.40	161.90	159.90	163.00
	Sub Mean	164.40	163.60	161.72	158.18	152.66	147.72	158.05	164.40	164.18	163.62	163.22	161.68	159.78	162.81
H ₂	T ₁	166.30	165.30	163.40	159.30	154.60	147.80	159.45	166.30	165.90	164.90	164.30	163.00	160.80	164.20
	T ₂	166.30	165.50	163.40	159.50	154.50	149.50	159.78	166.30	166.00	165.00	164.50	163.00	160.90	164.28
	T ₃	166.30	165.70	163.70	159.70	154.80	149.70	159.98	166.30	166.20	165.20	164.60	162.70	161.00	164.20
	T ₄	166.30	165.50	163.50	159.60	154.70	149.60	159.87	166.30	166.10	165.00	164.60	162.30	160.90	164.33
	T ₅	166.30	165.80	163.70	159.70	154.80	149.90	160.03	166.30	166.20	165.20	164.70	162.80	162.00	164.53
	Sub Mean	166.30	165.56	163.54	159.56	154.68	149.30	159.82	166.30	166.08	165.06	164.54	162.76	161.12	164.31
H ₃	T ₁	166.40	165.10	162.50	158.60	153.40	148.60	159.10	166.40	165.50	164.10	163.40	161.50	160.40	163.55
	T ₂	166.40	165.30	162.60	158.60	153.60	148.60	159.18	166.40	165.60	164.10	163.50	161.60	160.60	163.63
	T ₃	166.40	165.30	162.90	158.90	153.90	148.80	159.37	166.40	165.80	164.30	163.60	161.80	160.90	163.80
	T ₄	166.40	165.10	162.80	158.70	153.80	148.70	159.25	166.40	165.60	164.20	163.60	161.60	160.70	163.68
	T ₅	166.40	165.40	162.90	158.90	153.90	148.90	159.40	166.40	165.80	164.40	163.70	161.80	161.10	163.64
	Sub Mean	166.40	165.24	162.74	158.74	153.72	148.72	159.26	166.40	165.66	164.22	163.56	161.66	160.74	163.71
Grand Mean		166.40	165.27	162.83	158.80	153.82	148.78	159.32	166.40	165.71	164.28	163.62	161.71	160.87	163.76
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.123				Harvest (H) =			0.125			
		Treatment (T) =			0.120				Treatment (T) =			0.123			
		H x T =			0.123				H x T =			0.122			
		Storage (S) =			0.118				Storage (S) =			0.117			
		H x S =			0.116				H x S =			0.113			
		H x S x T =			0.113				H x S x T =			0.115			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

There was significant decrease in fruit weight during storage of 100 days under ambient conditions. Mean value fruit weight decreased from 166.40 g at 0 days to 148.78 g after 100 days of storage.

Under refrigerated conditions, a mean maximum fruit weight of 166.40 g was observed in H₃ and minimum of 164.40 g in H₁ at 0 days of storage (Table 4).

Among treatments, highest fruit weight of 163.00, 164.53 and 163.80 g was observed for T₅ while as T₁ recorded the lowest mean Fruit weight of 162.65, 164.20 and 163.55 g in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in fruit weight during storage of 100 days under ambient conditions. Mean value of fruit weight decreased from 166.40 g at 0 days to 160.87 g after 100 days of storage.

4.1.5 Fruit firmness (lb/inch²)

Data presented in Table 5 pertains to the effect of harvest dates, postharvest treatments and storage periods on fruit firmness of “Red Delicious” apple under ambient conditions. A mean maximum fruit firmness of 19.70 lb/inch² was observed in H₁ and minimum of 18.60 lb/inch² in H₃ at 0 days of storage.

A significant effect of postharvest treatments on fruit firmness was observed. Highest fruit firmness of 17.00, 16.63 and 16.25 lb/inch² was observed for T₅ while as T₁ recorded the lowest mean fruit firmness of 16.23, 15.85 and 15.48 lb/inch² in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in fruit firmness during storage of 100 days under ambient conditions. Mean value of fruit firmness decreased from 19.23 lb/inch² at 0 days to 13.23 lb/inch² after 100 days of storage.

Table 5 shows data pertaining to the effect of harvest dates, postharvest treatments and storage periods on fruit firmness of “Red Delicious” apple under refrigerated conditions. A mean maximum fruit firmness of 19.70 lb/inch² was observed in H₁ and minimum of 18.60 lb/inch² in H₃ at 0 days of storage.

Table-5 : Effect of harvest dates, post harvest treatments and storage conditions on fruit firmness (lb/inch²) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)								
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean		
H ₁	T ₁	19.70	18.40	16.80	15.40	14.20	12.90	16.23	19.70	18.90	18.20	17.30	16.20	15.50	17.63		
	T ₂	19.70	18.40	17.00	15.70	14.60	13.30	16.45	19.70	18.90	18.30	17.40	16.20	15.50	17.67		
	T ₃	19.70	18.70	17.60	16.20	15.00	13.60	16.80	19.70	19.10	18.60	17.60	16.40	15.80	17.87		
	T ₄	19.70	18.60	17.40	16.00	14.80	13.40	16.65	19.70	19.00	18.50	17.40	16.30	15.70	17.77		
	T ₅	19.70	18.90	17.70	16.60	15.40	13.70	17.00	19.70	19.20	18.70	17.80	16.60	16.00	18.00		
	Sub Mean	19.70	18.60	17.30	15.98	14.80	13.38	16.63	19.70	19.02	18.46	17.50	16.34	15.70	17.79		
H ₂	T ₁	19.40	17.70	16.10	15.10	13.90	12.90	15.85	19.40	18.60	17.50	16.90	16.30	15.70	17.40		
	T ₂	19.40	17.70	16.20	15.10	13.90	12.90	15.87	19.40	18.70	17.60	17.00	16.30	15.70	17.45		
	T ₃	19.40	17.90	16.70	15.60	14.50	13.40	16.00	19.40	18.90	17.90	17.40	16.50	15.90	17.67		
	T ₄	19.40	17.80	16.40	15.30	14.10	13.00	16.25	19.40	18.80	17.80	17.10	16.40	15.80	17.55		
	T ₅	19.40	18.10	17.10	16.00	15.00	14.20	16.63	19.40	18.90	18.10	17.60	16.80	16.30	17.85		
	Sub Mean	19.40	17.84	16.50	15.42	14.28	13.28	16.12	19.40	18.78	17.78	17.20	16.46	15.88	17.58		
H ₃	T ₁	18.60	17.30	16.00	14.80	13.50	12.70	15.48	18.60	17.90	17.00	16.40	15.80	15.30	16.83		
	T ₂	18.60	17.40	16.20	14.90	13.50	12.70	15.55	18.60	18.50	17.00	16.40	15.90	15.40	16.97		
	T ₃	18.60	17.60	16.50	15.30	13.80	13.00	15.80	18.60	18.10	17.30	16.60	16.10	15.50	17.03		
	T ₄	18.60	17.40	16.30	15.10	13.60	12.80	15.63	18.60	18.10	17.10	16.50	16.00	15.50	16.97		
	T ₅	18.60	17.80	16.80	15.70	14.70	13.90	16.25	18.60	18.30	17.40	16.70	16.20	15.60	17.13		
	Sub Mean	18.60	17.50	16.36	15.16	13.82	13.02	15.74	18.60	18.18	17.16	16.52	16.00	15.46	16.99		
Grand Mean	19.23	17.98	16.72	15.52	14.30	13.23	16.16	19.23	18.66	17.80	17.07	16.27	15.68	17.45			
		CD (p≤0.05)							CD (p≤0.05)								
		Harvest (H)			=	0.315				Harvest (H)			=	0.319			
		Treatment (T)			=	0.213				Treatment (T)			=	0.213			
		H x T			=	0.119				H x T			=	0.116			
		Storage (S)			=	0.221				Storage (S)			=	0.225			
		H x S			=	0.220				H x S			=	0.226			
		H x S x T			=	0.215				H x S x T			=	0.219			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Highest fruit firmness of 18.00, 17.85 and 17.13 lb/inch² was observed for T₅ while as T₁ recorded the lowest mean fruit firmness of 17.63, 17.40 and 16.83 lb/inch² in three harvest dates H₁, H₂ and H₃, respectively and postharvest treatments showed a significant effect on fruit firmness.

There was significant decrease in fruit firmness during storage of 100 days under refrigerated conditions. Mean value of fruit firmness decreased from 19.23 lb/inch² at 0 days to 15.68 lb/inch² after 100 days of storage.

4.1.6 L* a* b* colour (Hunter color Lab)

Data pertaining to effect of harvest dates, postharvest treatments and storage periods on Lab values of “Red Delicious” apple under ambient conditions is presented in Table 6, 6.1 and 6.2. A mean maximum L* value of 40.60 was observed in H₁ and minimum of 39.00 in H₂ where as maximum a* value of 31.72 was observed in H₃ and minimum of 30.50 in H₁ and the higher value b* 16.90 was observed in H₁ and lowest value of 15.20 in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on lab values. Highest L* of 43.04, 42.17 and 42.67 was observed for T₁ while T₅ recorded the lowest mean values of 42.32, 41.35 and 40.96 where as maximum a* values of 28.89, 29.06 and 30.03 was observed in T₅, while T₁ recorded the lowest values of 28.36, 28.52 and 28.86 and T₁ recorded maximum b* values of 19.21, 18.23 and 18.09 while as T₅ showed minimum values of 18.37, 17.87 and 17.20 in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in L* and b* values during storage of 100 days under ambient conditions. Mean value increased from 34.23 and 16.10 at 0 days to 38.00 and 20.85, respectively while as a* values decrease from 31.21 to 27.01 after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on lab values of “Red Delicious” apple under ambient conditions is presented in Table 6, 6.1 and 6.2. A mean maximum L* value of 40.62 was

Table-6 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (L*) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)								
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean		
H ₁	T ₁	40.60	41.21	42.50	43.80	44.20	45.90	43.04	40.50	40.92	41.70	42.66	41.96	42.30	41.67		
	T ₂	40.53	41.17	42.30	43.70	44.06	45.72	42.91	40.62	40.71	41.01	41.52	41.83	42.10	41.30		
	T ₃	40.55	41.10	42.21	43.50	43.90	45.60	42.81	40.60	40.65	41.00	41.40	41.62	41.92	41.20		
	T ₄	40.20	41.02	42.06	43.32	43.72	45.46	42.63	40.56	40.61	40.88	41.25	41.46	41.80	41.09		
	T ₅	40.00	40.90	41.10	43.11	43.50	45.30	42.32	40.50	40.55	40.80	41.00	41.30	41.50	40.94		
	Sub Mean	40.38	41.08	42.03	43.49	43.88	45.60	42.74	40.56	40.69	41.08	41.57	41.63	41.92	41.24		
H ₂	T ₁	39.50	40.25	41.50	42.86	43.70	44.90	42.12	39.20	39.92	40.50	41.67	41.93	42.10	40.89		
	T ₂	39.45	40.16	41.35	42.70	43.62	45.72	42.17	39.12	39.81	40.41	41.35	41.85	42.00	40.76		
	T ₃	39.35	40.02	41.22	42.55	43.10	45.60	41.97	39.05	39.85	40.00	40.50	41.00	41.70	40.35		
	T ₄	39.22	40.07	41.36	42.63	43.25	45.46	42.00	39.00	39.63	39.98	40.27	40.86	41.43	40.20		
	T ₅	39.00	39.00	40.40	41.31	43.10	45.30	41.35	38.90	39.45	39.82	40.18	40.70	41.10	40.03		
	Sub Mean	39.30	39.90	41.17	42.41	43.35	45.40	41.82	39.05	39.73	40.14	40.79	41.27	41.67	40.44		
H ₃	T ₁	39.62	41.22	41.90	43.15	44.50	45.60	42.67	39.35	39.80	40.40	41.00	41.76	42.60	40.82		
	T ₂	39.56	41.10	41.60	42.70	43.06	44.65	42.11	39.20	39.70	40.20	40.96	41.63	42.40	40.68		
	T ₃	39.40	40.70	41.41	42.50	43.20	44.36	41.93	39.12	39.54	40.05	40.65	41.42	42.22	40.50		
	T ₄	39.30	41.02	41.00	42.62	43.52	44.20	41.94	39.10	39.36	40.00	40.35	41.23	41.92	40.33		
	T ₅	39.00	39.90	40.60	41.21	42.05	43.00	40.96	39.00	39.15	39.97	40.10	41.07	41.46	40.13		
	Sub Mean	39.38	40.79	41.30	42.44	43.27	44.36	41.92	39.15	39.51	40.12	40.61	41.42	42.12	40.49		
Grand Mean	34.23	34.66	35.40	36.30	36.74	38.00	35.89	34.20	34.47	34.74	35.12	35.30	35.53	34.89			
		CD (p≤0.05)							CD (p≤0.05)								
		Harvest (H)			=	0.07				Harvest (H)			=	0.05			
		Treatment (T)			=	0.06				Treatment (T)			=	0.04			
		H x T			=	0.10				H x T			=	0.08			
		Storage (S)			=	0.09				Storage (S)			=	0.07			
		H x S			=	0.04				H x S			=	0.04			
		H x S x T			=	0.12				H x S x T			=	0.10			

L* = indicates brightness or lightness (0=black and 100 = white)

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-6.1 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (a*) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	30.5	29.26	28.9	28.02	27.1	26.4	28.36	30.3	29.7	29.5	29	28.7	27.15	29.06
	T ₂	30.51	29.4	28.98	28.2	27.2	26.62	28.49	30.34	29.9	29.55	29.1	28.9	27.6	29.23
	T ₃	30.53	29.5	29.2	28.32	27.35	26.8	28.62	30.36	29.96	29.63	29.22	29	27.9	29.35
	T ₄	30.56	29.8	29.5	28.55	27.46	26.96	28.81	30.4	29.98	29.8	29.36	29.22	28.1	29.48
	T ₅	30.6	30.02	29.7	28.63	27.26	27.1	28.89	40.46	30	29.96	29.15	29.36	28.4	31.22
	Sub Mean	30.54	29.60	29.26	28.34	27.27	26.78	28.63	32.37	29.91	29.69	29.17	29.04	27.83	29.67
H ₂	T ₁	31.5	29.26	28.62	27.92	27.3	26.5	28.52	31.7	31.2	30.55	30	29.6	29.17	30.37
	T ₂	31.51	29.3	28.78	27.97	27.4	26.62	28.60	31.74	31.3	30.65	30.1	29.7	29.45	30.49
	T ₃	31.56	29.44	28.92	28.02	27.9	26.8	28.77	31.66	31.16	30.73	30.23	29.83	29.22	30.47
	T ₄	31.46	29.35	28.8	28	27.35	26.96	28.65	31.7	31	30.81	30.46	29.92	29.3	30.53
	T ₅	31.62	30.02	29.7	28.33	27.56	27.1	29.06	31.93	31.42	31.05	30.8	30.32	29.8	30.89
	Sub Mean	31.53	29.47	28.96	28.05	27.50	26.80	28.72	31.75	31.22	30.76	30.32	29.87	29.39	30.55
H ₃	T ₁	31.52	30.26	29.9	28.22	27.15	26.1	28.86	31.73	31.23	29.5	28.67	27.65	27.1	29.31
	T ₂	31.41	30.42	29.99	29.05	28.25	27.32	29.41	31.8	31.4	29.65	28.8	27.7	27.25	29.43
	T ₃	31.54	30.5	30.1	29.72	28.55	27.7	29.69	31.86	31.56	29.8	29	28.2	27.42	29.64
	T ₄	31.65	31	30	29.55	28.4	27.86	29.74	31.93	31.65	30	29.46	28.46	27.83	29.89
	T ₅	31.72	31.05	30.5	29.65	29	28.24	30.03	32.02	31.76	31	30.21	29.25	28.27	30.42
	Sub Mean	31.57	30.65	30.10	29.24	28.27	27.44	29.54	31.87	31.52	29.99	29.23	28.25	27.57	29.74
Grand Mean	31.21	29.91	29.44	28.54	27.68	27.01	28.96	32.00	30.88	30.15	29.57	29.05	28.26	29.99	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			=	0.08			Harvest (H)			=	0.09		
		Treatment (T)			=	0.11			Treatment (T)			=	0.13		
		H x T			=	0.13			H x T			=	0.15		
		Storage (S)			=	0.14			Storage (S)			=	0.16		
		H x S			=	0.05			H x S			=	0.07		
		H x S x T			=	0.16			H x S x T			=	0.18		

a* = indicates chromaticity on green (-ve) to red (+ve) axis

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-6.2 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (b*) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	16.90	17.95	18.70	19.21	20.50	22.00	19.21	16.95	17.70	17.90	18.50	18.93	20.32	18.38
	T ₂	16.90	17.95	18.50	19.11	20.41	21.80	19.11	16.92	17.60	17.80	18.46	18.80	20.00	18.26
	T ₃	16.85	17.90	18.28	19.00	20.11	21.60	18.96	16.90	17.52	17.72	18.35	18.72	19.92	18.19
	T ₄	16.80	17.85	18.10	18.80	20.00	21.43	18.83	16.86	17.41	17.61	18.18	18.40	19.70	18.03
	T ₅	16.85	16.88	17.00	18.71	19.70	21.10	18.37	16.80	17.20	17.50	18.06	18.20	19.41	17.86
	Sub Mean	16.86	17.71	18.12	18.97	20.14	21.59	18.90	16.89	17.49	17.71	18.31	18.61	19.87	18.14
H ₂	T ₁	15.90	16.90	17.90	18.31	19.30	20.35	18.11	15.65	16.40	17.22	17.77	18.13	18.62	17.30
	T ₂	16.10	16.65	17.50	18.13	19.20	21.80	18.23	15.35	16.66	17.10	17.65	18.00	18.51	17.21
	T ₃	16.00	16.30	17.38	18.00	19.11	21.60	18.07	15.90	16.52	16.92	17.35	17.72	18.32	17.12
	T ₄	16.20	16.22	17.46	18.10	19.00	21.43	18.07	15.81	16.37	16.61	17.14	17.50	18.11	16.92
	T ₅	15.85	16.68	17.00	17.91	18.70	21.10	17.87	15.70	16.22	16.54	16.96	17.31	17.92	16.78
	Sub Mean	16.01	16.55	17.45	18.09	19.06	21.26	18.07	15.68	16.43	16.88	17.37	17.73	18.30	17.07
H ₃	T ₁	15.94	16.95	17.60	18.26	19.25	20.56	18.09	15.75	16.30	16.90	17.25	18.10	18.90	17.20
	T ₂	15.40	16.45	17.30	18.10	19.21	20.10	17.76	15.40	16.10	16.80	17.15	18.00	18.60	17.01
	T ₃	15.20	16.10	16.88	17.40	18.15	19.50	17.21	15.28	16.00	16.62	17.00	17.82	18.42	16.86
	T ₄	15.40	16.65	17.10	17.88	18.35	19.43	17.47	15.12	15.92	16.40	16.96	17.52	18.22	16.69
	T ₅	15.20	16.36	17.00	17.60	18.15	18.90	17.20	15.00	15.60	16.21	16.76	17.30	18.00	16.48
	Sub Mean	15.43	16.50	17.18	17.85	18.62	19.70	17.55	15.31	15.98	16.59	17.02	17.75	18.43	16.85
Grand Mean		16.10	16.92	17.58	18.30	19.28	20.85	18.17	15.96	16.63	17.06	17.57	18.03	18.86	17.35
		CD (p=0.05)							CD (p=0.05)						
		Harvest (H) =			0.21				Harvest (H) =			0.18			
		Treatment (T) =			0.11				Treatment (T) =			0.10			
		H x T =			0.13				H x T =			0.11			
		Storage (S) =			0.17				Storage (S) =			0.15			
		H x S =			0.19				H x S =			0.16			
		H x S x T =			0.24				H x S x T =			0.20			

b* = indicates chromaticity on blue (-ve) to yellow (+ve) axis

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

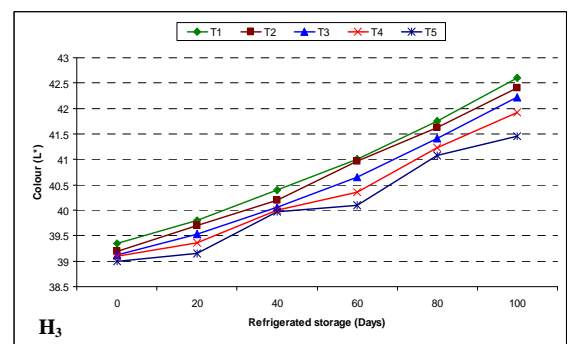
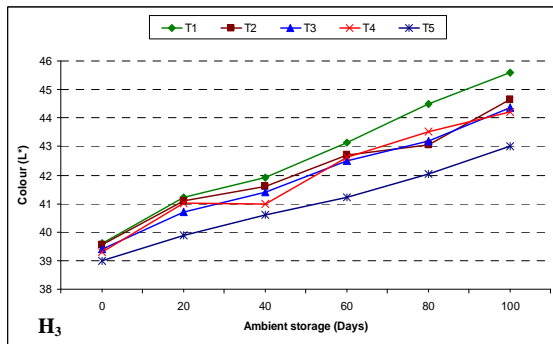
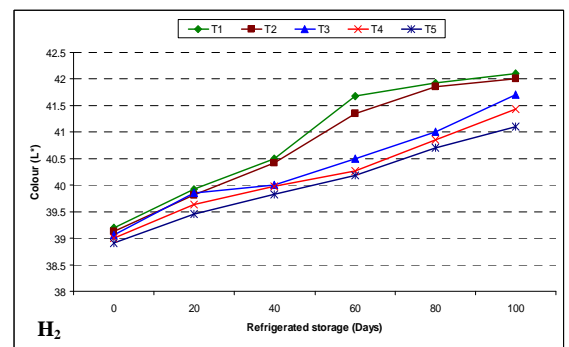
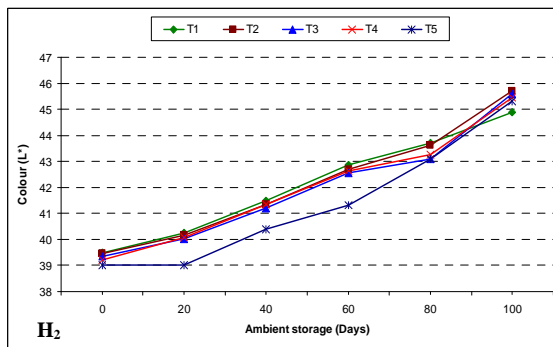
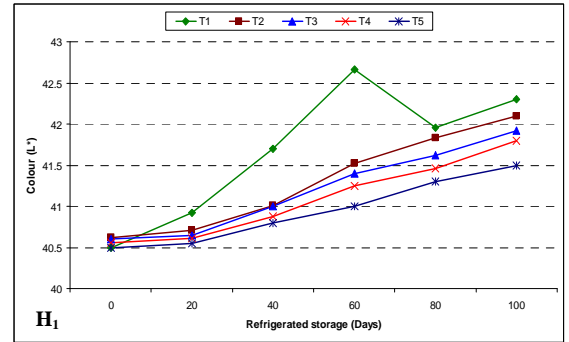
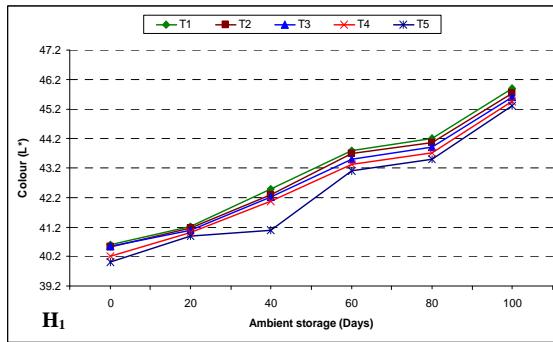


Fig. 1 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (L*) of apple

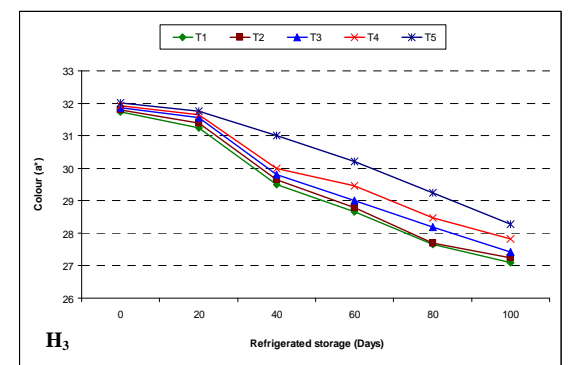
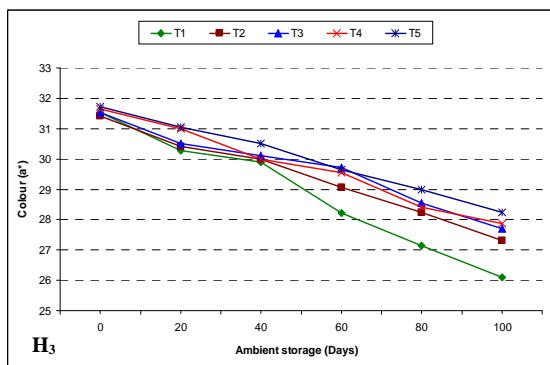
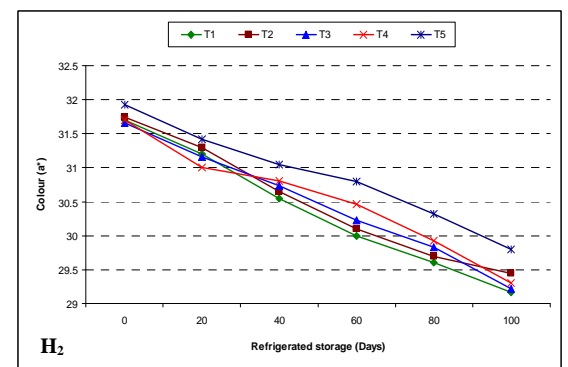
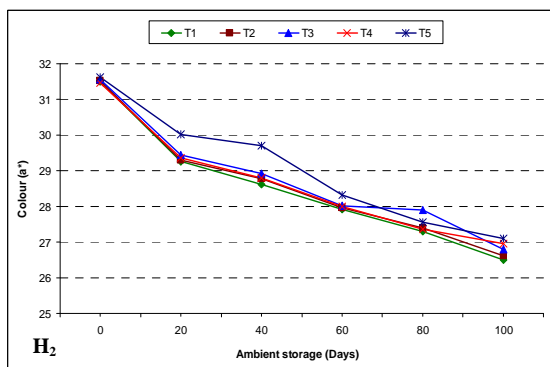
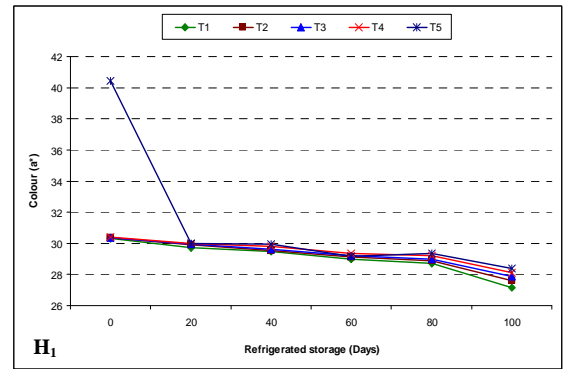
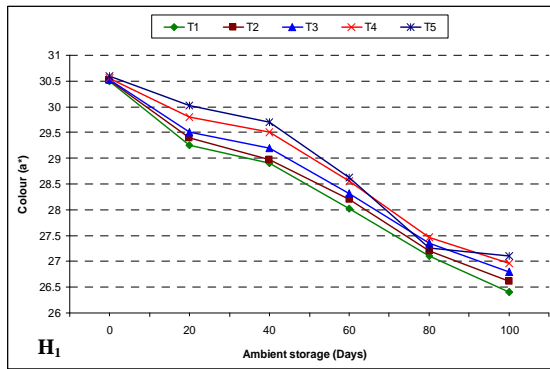


Fig. 2 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (a^*) of apple

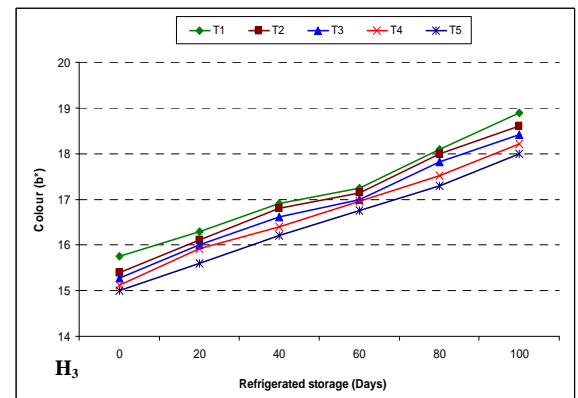
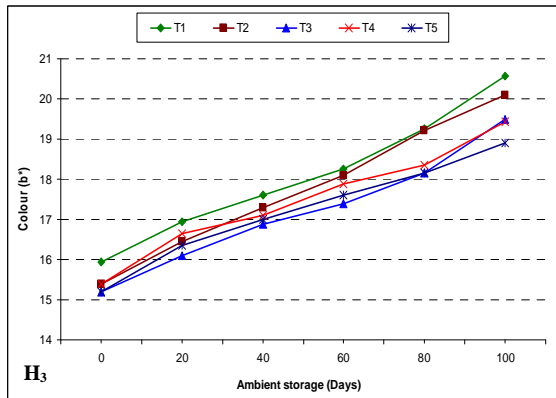
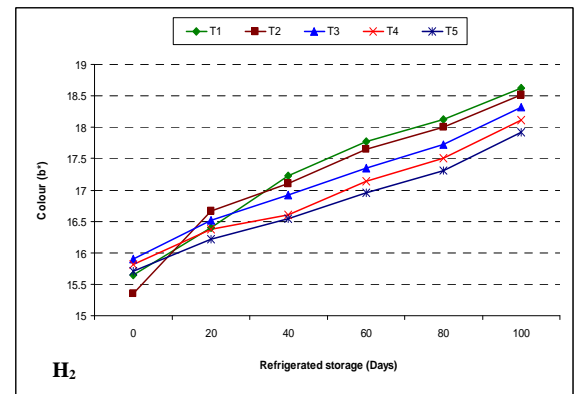
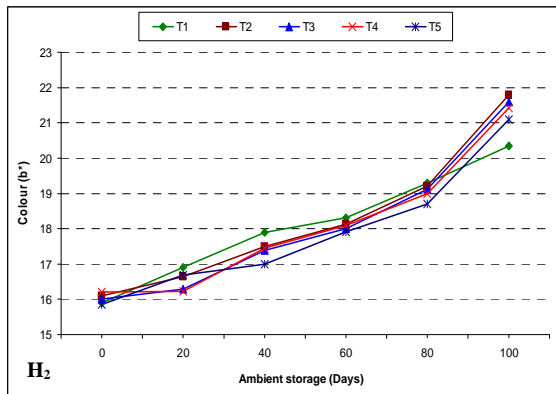
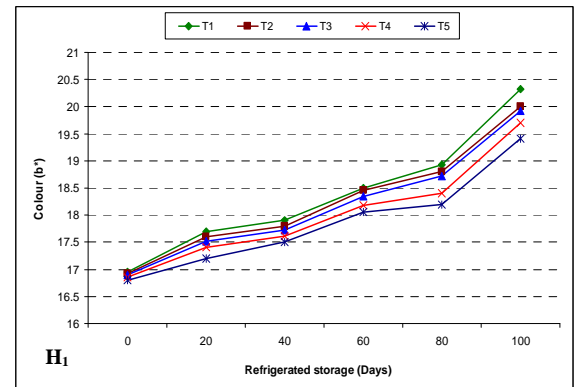
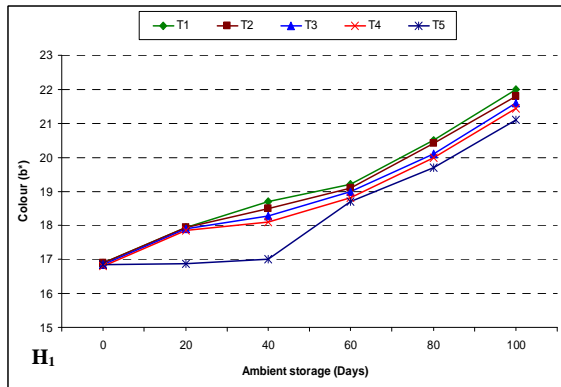


Fig. 3 : Effect of harvest dates, post harvest treatments and storage conditions on Colour (b*) of apple

observed in H₁ and minimum of 39.00 in H₃, whereas maximum a* value of 32.02 was observed in H₃ and minimum of 30.30 in H₁ and the higher value of b* of 16.95 was observed in H₁ and lowest of 15.00 in H₃ at 0 day of storage.

Postharvest treatments showed a significant effect on lab values. Highest L* of 41.67, 40.89 and 40.82 was observed for T₁ while as T₅ recorded the lowest mean of 40.94, 40.03 and 40.13 where as maximum a* values of 31.22, 30.89 and 30.42 was observed in T₅ while as T₁ recorded the lowest values of 29.06, 30.37 and 29.31 and T₁ recorded maximum b* values of 18.38, 17.30 and 17.20 while as T₅ showed minimum values of 17.86, 16.78 and 16.48 in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in L* and b* values during storage of 100 days under refrigerated conditions. Mean value increased from 34.20 and 15.96 at 0 days to 35.53 and 18.86 respectively, while a* values decreased from 32.00 to 28.26 after 100 days of storage.

4.1.7 Rot incidence (%)

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on per cent rot incidence of “Red Delicious” apple under ambient conditions is presented in Table 7. A mean maximum per cent rot incidence of 0.00 was observed in all harvest dates at 0 days of storage.

T₁ recorded the highest per cent rot incidence of 1.40, 1.44 and 1.57 while as T₅ recorded the lowest mean per cent rot incidence of 1.01, 1.07 and 1.13 in three harvest dates H₁, H₂ and H₃, respectively. Postharvest treatments showed a significant effect on per cent rot incidence.

There was significant increase in per cent rot incidence during storage of 100 days under ambient conditions. Mean value of per cent rot incidence increased from 0.00 at 0 days to 3.86 after 100 days of storage.

Table 7 gives data pertaining to effect of harvest dates, postharvest treatments and storage periods on per cent rot incidence of “Red Delicious” apple

Table-7 : Effect of harvest dates, post harvest treatments and storage conditions on rot incidence (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	0.00	0.31	0.81	1.31	2.41	4.11	1.49	0.00	0.13	0.31	0.81	1.41	1.91	0.76
	T ₂	0.00	0.21	0.81	1.31	2.41	4.01	1.46	0.00	0.11	0.12	0.71	1.41	1.91	0.71
	T ₃	0.00	0.11	0.61	0.91	1.91	3.61	1.19	0.00	0.00	0.11	0.51	1.21	1.71	0.59
	T ₄	0.00	0.11	0.61	1.01	1.91	3.71	1.23	0.00	0.01	0.13	0.61	1.21	1.71	0.61
	T ₅	0.00	0.11	0.41	0.61	1.31	3.61	1.01	0.00	0.01	0.01	0.51	1.11	1.51	0.53
	Sub Mean	0.00	0.17	0.65	1.03	1.99	3.81	1.28	0.00	0.05	0.14	0.63	1.27	1.75	0.64
H ₂	T ₁	0.00	0.20	0.70	1.30	2.40	4.00	1.44	0.00	0.10	0.40	0.90	1.30	1.80	0.75
	T ₂	0.00	0.20	0.70	1.30	2.40	3.80	1.40	0.00	0.10	0.30	0.90	1.30	1.70	0.72
	T ₃	0.00	0.00	0.50	0.80	2.00	3.60	1.15	0.00	0.00	0.10	0.50	1.20	1.50	0.55
	T ₄	0.00	0.10	0.50	1.00	2.10	3.80	1.25	0.00	0.01	0.21	0.71	1.21	1.51	0.61
	T ₅	0.00	0.00	0.30	0.80	1.80	3.50	1.07	0.00	0.01	0.11	0.51	1.11	1.41	0.53
	Sub Mean	0.00	0.10	0.54	1.04	2.14	3.74	1.26	0.00	0.05	0.23	0.71	1.23	1.59	0.63
H ₃	T ₁	0.00	0.32	0.82	1.42	2.52	4.32	1.57	0.00	0.12	0.32	0.92	1.52	1.22	0.68
	T ₂	0.00	0.22	0.82	1.42	2.52	4.22	1.53	0.00	0.12	0.22	0.92	1.62	1.82	0.78
	T ₃	0.00	0.12	0.72	1.02	1.72	3.92	1.25	0.00	0.02	0.12	0.62	1.32	1.72	0.63
	T ₄	0.00	0.12	0.72	1.12	2.02	4.02	1.33	0.00	0.02	0.12	0.72	1.32	1.72	0.65
	T ₅	0.00	0.12	0.52	0.72	1.72	3.72	1.13	0.00	0.02	0.12	0.52	1.22	1.62	0.58
	Sub Mean	0.00	0.18	0.72	1.14	2.10	4.04	1.36	0.00	0.06	0.18	0.74	1.40	1.62	0.67
Grand Mean		0.00	0.15	0.64	1.07	2.08	3.86	1.30	0.00	0.05	0.18	0.69	1.30	1.65	0.65
CD (p≤0.05)							CD (p≤0.05)								
			Harvest (H) = 0.054							Harvest (H) = 0.043					
			Treatment (T) = 0.010							Treatment (T) = 0.012					
			H x T = 0.006							H x T = 0.004					
			Storage (S) = 0.025							Storage (S) = 0.022					
			H x S = 0.021							H x S = 0.019					
			H x S x T = 0.018							H x S x T = 0.020					

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

under refrigerated conditions. A mean maximum per cent rot incidence of 0.00 was observed in all harvest dates at 0 days of storage.

Postharvest treatments showed a significant effect on Percent Rot incidence. Highest per cent rot incidence of 0.73, 0.75 and 0.78 was observed for T₁ while as T₅ recorded the lowest mean per cent rot incidence of 0.53, 0.53 and 0.58 in three harvest dates H₁, H₂ and H₃ respectively.

Mean value of per cent rot incidence increased significantly from 0.00 at 0 days to 1.65 after 100 days of storage under refrigerated conditions.

4.1.8 Physiological loss in weight (%)

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on physiological loss in weight of “Red Delicious” apple under ambient conditions is presented in Table 8. A mean maximum physiological loss in weight of 0.00 per cent was observed in all harvest dates at 0 day of storage.

Postharvest treatments showed a significant effect on physiological loss in weight. Highest physiological loss in weight of 8.74, 8.43 and 8.45 per cent was observed in T₁ while as T₅ recorded the lowest mean physiological loss in weight of 8.29, 8.06 and 8.27 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in physiological loss in weight during storage of 100 days under ambient conditions. Mean value of Percent physiological weight loss increased from 0.00 per cent at 0 day to 16.55 per cent after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on physiological loss in weight of “Red Delicious” apple under refrigerated conditions is presented in Table 8. A mean maximum physiological loss in weight of 0.00 per cent was observed in all harvest dates at 0 days of storage.

Table-8 : Effect of harvest dates, post harvest treatments and storage conditions on rot Physiological loss in weight (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	0.00	3.57	7.67	10.47	13.67	17.07	8.74	0.00	1.67	2.47	3.67	4.87	5.97	3.11
	T ₂	0.00	3.47	7.67	10.37	13.47	17.07	8.68	0.00	1.57	2.37	3.57	4.67	5.77	2.99
	T ₃	0.00	3.17	7.47	10.27	13.47	16.97	8.56	0.00	1.47	2.37	3.57	4.57	5.67	2.94
	T ₄	0.00	2.77	7.07	10.07	13.07	16.77	8.29	0.00	1.47	2.17	3.17	4.57	5.67	2.84
	T ₅	0.00	3.07	7.37	1.27	13.47	16.97	7.03	0.00	1.37	2.17	3.07	4.27	5.57	2.74
	Sub Mean	0.00	3.21	7.45	8.49	13.43	16.97	8.26	0.00	1.51	2.31	3.41	4.59	5.73	2.93
H ₂	T ₁	0.00	3.35	7.55	10.25	13.05	16.35	8.43	0.00	1.55	2.35	3.35	4.65	5.35	2.88
	T ₂	0.00	3.25	7.45	10.15	13.05	16.25	8.36	0.00	1.55	2.25	3.25	4.55	5.25	2.81
	T ₃	0.00	3.15	7.35	10.05	12.95	16.35	8.31	0.00	1.45	2.25	3.25	4.55	5.25	2.79
	T ₄	0.00	3.05	7.35	9.75	12.85	16.15	8.19	0.00	1.35	2.15	3.15	4.45	5.15	2.71
	T ₅	0.00	2.95	7.05	9.55	12.75	16.05	8.06	0.00	1.25	2.05	3.05	4.25	5.05	2.61
	Sub Mean	0.00	3.15	7.35	9.95	12.93	16.23	8.27	0.00	1.43	2.21	3.21	4.49	5.21	2.76
H ₃	T ₁	0.00	3.26	7.36	10.36	13.16	16.56	8.45	0.00	1.36	2.26	3.46	4.76	5.66	2.92
	T ₂	0.00	3.16	7.26	10.36	13.16	16.56	8.42	0.00	1.36	2.16	3.36	4.66	5.56	2.85
	T ₃	0.00	3.06	7.16	10.26	12.96	16.46	8.32	0.00	1.26	2.16	3.36	4.66	5.56	2.83
	T ₄	0.00	2.96	7.16	10.16	12.96	16.36	8.27	0.00	1.26	2.06	3.26	4.56	5.46	2.77
	T ₅	0.00	2.86	7.86	10.16	12.76	16.36	8.33	0.00	1.06	2.06	3.06	4.36	5.46	2.67
	Sub Mean	0.00	3.06	7.36	10.26	13.00	16.46	8.36	0.00	1.26	2.14	3.30	4.60	5.54	2.81
Grand Mean	0.00	3.14	7.39	9.57	13.12	16.55	8.29	0.00	1.40	2.22	3.31	4.56	5.49	2.83	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.015				Harvest (H) =			0.015			
		Treatment (T) =			0.017				Treatment (T) =			0.013			
		H x T =			0.105				H x T =			0.106			
		Storage (S) =			1.004				Storage (S) =			1.004			
		H x S =			1.005				H x S =			1.007			
		H x S x T =			1.035				H x S x T =			1.028			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Postharvest treatments showed a significant effect on physiological loss in weight. Highest physiological loss in weight of 3.11, 2.88 and 2.92 per cent was observed in T₁ while T₅ recorded the lowest mean physiological loss in weight of 2.74, 2.61 and 2.67 per cent in three harvest dates H₁, H₂ & H₃, respectively.

There was significant increase in physiological loss in weight during storage of 100 days under refrigerated conditions. Mean value of physiological loss in weight increased from 0.00 per cent at 0 days to 5.49 per cent after 100 days of storage.

4.2 Chemical properties

4.2.1 Moisture content (%)

Among three harvest dates studied, a mean maximum per cent moisture of 82.60 was observed in H₁ and minimum of 80.89 in H₃ at 0 days of storage (Table 9).

There was a significant effect of postharvest treatments on per cent moisture. Highest per cent moisture of 75.13, 75.00 and 74.17 was observed in T₅, while T₁ recorded the lowest mean per cent moisture of 74.82, 74.51 and 73.96 in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in per cent moisture during storage of 100 days under ambient conditions. Mean value of per cent moisture increased from 81.78 at 0 days to 65.98 after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on per cent moisture of “Red Delicious” apple under refrigerated conditions is presented in Table 9. A mean maximum per cent moisture of 82.60 was observed in H₁ and minimum of 80.89 in H₃ at 0 day of storage.

Postharvest treatments showed a significant effect on per cent moisture. Highest per cent moisture of 79.33, 79.57 and 78.89 was observed in T₅ while as

Table-9 : Effect of harvest dates, post harvest treatments and storage conditions on moisture content (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	82.60	79.80	77.30	74.00	69.60	65.60	74.82	82.60	81.10	79.20	70.20	77.70	76.60	77.90
	T ₂	82.60	79.90	77.40	74.00	69.70	65.70	74.88	82.60	80.90	78.90	78.00	77.40	76.40	79.03
	T ₃	82.60	80.20	77.60	74.10	69.90	65.90	75.05	82.60	81.00	79.10	78.10	77.60	76.60	79.17
	T ₄	82.60	80.10	77.50	74.10	69.80	65.80	74.98	82.60	81.00	79.00	78.00	77.50	76.50	79.10
	T ₅	82.60	80.20	77.80	74.20	70.00	66.00	75.13	82.60	81.20	79.30	78.30	77.80	76.80	79.33
	Sub Mean	82.60	80.04	77.52	74.08	69.80	65.80	74.97	82.60	81.04	79.10	76.52	77.60	76.58	78.91
H ₂	T ₁	81.84	79.44	76.64	73.04	69.84	66.24	74.51	81.84	80.94	79.54	78.54	77.84	77.04	79.29
	T ₂	81.84	79.54	76.64	73.04	69.94	66.34	74.56	81.84	81.14	79.64	78.74	78.04	77.14	79.42
	T ₃	81.84	79.74	76.84	73.24	70.14	66.64	74.74	81.84	81.24	79.84	78.94	78.24	77.24	79.56
	T ₄	81.84	79.64	76.74	73.14	70.04	66.44	74.64	81.84	81.14	79.74	78.84	78.14	77.24	79.49
	T ₅	81.84	79.84	76.84	73.34	70.14	66.84	75.00	81.84	81.34	79.94	78.74	78.24	77.34	79.57
	Sub Mean	81.84	79.64	76.74	73.16	70.02	66.50	74.65	81.84	81.16	79.74	78.76	78.10	77.20	79.47
H ₃	T ₁	80.89	78.89	76.39	72.49	69.59	65.49	73.96	80.89	80.09	77.09	79.09	77.79	76.79	78.62
	T ₂	80.89	78.99	75.99	72.69	69.59	65.59	73.96	80.89	80.19	77.19	79.09	77.89	76.89	78.69
	T ₃	80.89	79.09	76.19	72.89	69.69	65.69	74.07	80.89	79.89	78.99	78.89	77.69	76.59	78.82
	T ₄	80.89	78.99	76.09	72.79	69.69	65.59	74.01	80.89	79.89	78.89	78.79	77.59	76.49	78.76
	T ₅	80.89	79.09	76.39	72.99	69.79	65.89	74.17	80.89	79.99	79.09	78.99	77.69	76.69	78.89
	Sub Mean	80.89	79.01	76.21	72.77	69.67	65.65	74.03	80.89	80.01	78.25	78.97	77.73	76.69	78.76
Grand Mean		81.78	79.56	76.82	73.34	69.83	65.98	74.55	81.78	80.74	79.03	78.08	77.81	76.82	79.04
CD (p≤0.05)							CD (p≤0.05)								
			Harvest (H)	=	0.013						Harvest (H)	=	0.003		
			Treatment (T)	=	0.008						Treatment (T)	=	0.006		
			H x T	=	0.026						H x T	=	0.023		
			Storage (S)	=	0.106						Storage (S)	=	0.107		
			H x S	=	0.102						H x S	=	0.109		
			H x S x T	=	0.114						H x S x T	=	0.103		

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

T₁ recorded the lowest mean per cent moisture of 77.90, 79.29 and 78.62 in three harvest dates H₁, H₂ and H₃ respectively.

Mean value of per cent moisture increased from 81.78 at 0 days to 76.82 after 100 days of storage. There was significant increase in per cent moisture during storage of 100 days under refrigerated conditions.

4.2.2 Total soluble solids (°Brix)

Effect of harvest dates, postharvest treatments and storage periods on TSS of “Red Delicious” apple under ambient conditions was studied and data is presented in Table 10. A mean maximum TSS of 14.84 °Brix was observed in H₃ and minimum of 14.17 °Brix in H₁ at 0 day of storage.

A significant effect of postharvest treatments was observed on TSS. Highest TSS of 16.39, 16.13 and 16.91 °Brix was observed for T₁, while T₅ recorded the lowest mean TSS of 15.70, 15.35 and 16.16 °Brix in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in TSS during storage of 100 days under ambient conditions. Mean value of TSS increased from 14.46 °Brix at 0 days to 17.92 °Brix after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on TSS of “Red Delicious” apple under refrigerated conditions is presented in Table 10. A mean maximum TSS of 14.84 °Brix was observed in H₃ and minimum of 14.17 °Brix in H₁ at 0 day of storage.

Postharvest treatments showed a significant effect on TSS. Highest TSS of 15.09, 15.33 and 16.17 °Brix was observed for T₁ while T₅ recorded the lowest mean TSS of 14.40, 14.80 and 15.45 °Brix in three harvest dates H₁, H₂ and H₃, respectively.

Table-10 : Effect of harvest dates, post harvest treatments and storage conditions on TSS content (°Brix) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	14.17	15.17	15.97	16.87	17.77	18.37	16.39	14.17	14.67	15.07	15.47	16.07	16.50	15.09
	T ₂	14.17	14.77	15.47	16.37	17.47	18.17	16.07	14.17	14.47	14.87	15.27	15.87	16.20	14.93
	T ₃	14.17	14.67	15.17	16.17	17.27	17.77	15.87	14.17	14.27	14.57	14.97	15.37	15.60	14.67
	T ₄	14.17	14.77	15.47	16.57	17.47	18.07	16.09	14.17	14.57	14.97	15.37	15.77	16.10	14.97
	T ₅	14.17	14.47	15.27	16.07	16.77	17.47	15.70	14.17	14.27	14.47	14.77	15.07	16.02	14.40
	Sub Mean	14.17	14.77	15.47	16.41	17.35	17.97	16.02	14.17	14.45	14.79	15.17	15.63	16.02	15.04
H ₂	T ₁	14.38	14.98	15.58	16.38	17.28	18.18	16.13	14.38	14.88	15.18	15.38	15.88	16.30	15.33
	T ₂	14.38	14.78	15.38	16.08	16.88	17.88	15.90	14.38	14.68	15.08	15.18	15.68	16.00	15.17
	T ₃	14.38	14.48	14.98	15.28	16.48	17.38	15.50	14.38	14.48	14.88	15.08	15.38	15.60	14.97
	T ₄	14.38	14.68	15.18	16.08	16.68	17.58	15.76	14.38	14.68	15.18	15.38	15.58	15.90	15.18
	T ₅	14.38	14.58	14.58	15.38	16.18	16.98	15.35	14.38	14.78	14.98	15.18	15.38	15.40	14.80
	Sub Mean	14.38	14.70	15.14	15.84	16.70	17.60	15.73	14.27	14.56	14.91	15.20	15.58	15.84	15.06
H ₃	T ₁	14.84	15.74	16.54	17.34	18.14	18.84	16.91	14.84	15.34	15.94	16.34	17.14	17.40	16.17
	T ₂	14.84	15.74	16.24	17.04	17.84	18.54	16.71	14.84	15.24	15.74	16.24	16.94	17.20	16.03
	T ₃	14.84	15.34	16.04	16.54	17.14	17.64	16.26	14.84	15.04	15.34	15.74	16.24	16.30	15.58
	T ₄	14.84	15.54	16.34	17.14	17.74	18.44	16.67	14.84	15.34	15.84	16.34	16.84	17.00	16.03
	T ₅	14.84	15.24	15.84	16.54	17.04	17.44	16.16	14.84	15.04	15.24	15.54	15.94	16.10	15.45
	Sub Mean	14.84	15.52	16.20	16.92	17.58	18.18	16.54	14.84	15.20	15.62	16.04	16.62	16.80	15.85
Grand Mean	14.46	15.00	15.60	16.39	17.21	17.92	16.10	14.43	14.74	15.11	15.47	15.94	16.22	15.32	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.266				Harvest (H) =			0.283			
		Treatment (T) =			0.209				Treatment (T) =			0.219			
		H x T =			0.328				H x T =			0.323			
		Storage (S) =			0.312				Storage (S) =			0.305			
		H x S =			0.223				H x S =			0.219			
		H x S x T =			0.259				H x S x T =			0.237			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

During storage of 100 days under refrigerated conditions, there was a significant increase in TSS. Mean value of TSS increased from 14.43 °Brix at 0 day to 16.22 °Brix after 100 days of storage.

4.2.3 Acidity (%)

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on acidity of “Red Delicious” apple under ambient conditions is depicted in Table 11. A mean maximum acidity of 0.363 per cent was observed in H₁ and minimum of 0.330 per cent in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on acidity. Highest Acidity of 0.335, 0.327 and 0.295 per cent was observed for T₅ while as T₁ recorded the lowest mean Acidity of 0.294, 0.298 and 0.267 per cent in three harvest dates H₁, H₂ and H₃ respectively.

There was significant decrease in acidity during storage of 100 days under ambient conditions. Mean value of acidity decreased from 0.348 per cent at 0 days to 0.239 per cent after 100 days of storage.

Acidity of “Red Delicious” apple under refrigerated conditions as influenced by harvest dates, postharvest treatments and storage periods was studied and data presented in Table 11. A mean maximum acidity of 0.364 per cent was observed in H₁ and minimum of 0.330 per cent in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on acidity. Highest acidity of 0.344, 0.340 and 0.312 per cent was observed in T₅ while as T₁ recorded the lowest mean acidity of 0.324, 0.314 and 0.286 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in acidity during storage of 100 days under refrigerated conditions. Mean value of acidity decreased from 0.348 per cent at 0 days to 0.280 per cent after 100 days of storage.

Table-11 : Effect of harvest dates, post harvest treatments and storage conditions on acidity (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)								
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean		
H ₁	T ₁	0.363	0.347	0.314	0.277	0.248	0.216	0.294	0.364	0.349	0.338	0.316	0.304	0.274	0.324		
	T ₂	0.363	0.349	0.318	0.281	0.257	0.238	0.301	0.364	0.349	0.343	0.328	0.319	0.285	0.331		
	T ₃	0.363	0.359	0.341	0.312	0.288	0.262	0.321	0.364	0.354	0.349	0.340	0.323	0.315	0.341		
	T ₄	0.363	0.356	0.337	0.304	0.279	0.255	0.316	0.364	0.351	0.344	0.334	0.320	0.306	0.337		
	T ₅	0.363	0.357	0.344	0.338	0.317	0.292	0.335	0.364	0.354	0.351	0.343	0.331	0.321	0.344		
	Sub Mean	0.363	0.354	0.331	0.302	0.278	0.253	0.313	0.364	0.351	0.345	0.332	0.319	0.300	0.335		
H ₂	T ₁	0.351	0.335	0.320	0.288	0.267	0.227	0.298	0.351	0.343	0.335	0.296	0.283	0.277	0.314		
	T ₂	0.351	0.339	0.322	0.295	0.272	0.236	0.303	0.351	0.345	0.338	0.302	0.294	0.287	0.320		
	T ₃	0.351	0.345	0.340	0.315	0.292	0.265	0.318	0.351	0.347	0.343	0.335	0.327	0.320	0.337		
	T ₄	0.351	0.342	0.335	0.310	0.285	0.260	0.314	0.351	0.346	0.341	0.332	0.321	0.310	0.334		
	T ₅	0.350	0.347	0.342	0.320	0.305	0.298	0.327	0.350	0.348	0.345	0.339	0.332	0.327	0.340		
	Sub Mean	0.351	0.342	0.332	0.306	0.284	0.257	0.312	0.351	0.346	0.340	0.321	0.311	0.304	0.329		
H ₃	T ₁	0.330	0.316	0.275	0.254	0.225	0.200	0.267	0.330	0.320	0.310	0.273	0.256	0.229	0.286		
	T ₂	0.330	0.318	0.281	0.260	0.229	0.203	0.270	0.330	0.322	0.312	0.278	0.260	0.233	0.289		
	T ₃	0.330	0.319	0.383	0.262	0.232	0.205	0.289	0.330	0.325	0.316	0.284	0.267	0.238	0.293		
	T ₄	0.330	0.321	0.288	0.266	0.235	0.208	0.275	0.330	0.323	0.314	0.281	0.263	0.234	0.291		
	T ₅	0.330	0.322	0.391	0.270	0.239	0.217	0.295	0.330	0.325	0.318	0.387	0.269	0.241	0.312		
	Sub Mean	0.330	0.319	0.324	0.262	0.232	0.207	0.279	0.330	0.323	0.314	0.301	0.263	0.235	0.294		
Grand Mean	0.348	0.338	0.329	0.290	0.265	0.239	0.301	0.348	0.340	0.333	0.318	0.298	0.280	0.320			
		CD (p≤0.05)							CD (p≤0.05)								
		Harvest (H)			=	0.014				Harvest (H)			=	0.012			
		Treatment (T)			=	0.015				Treatment (T)			=	0.013			
		H x T			=	0.012				H x T			=	0.016			
		Storage (S)			=	0.011				Storage (S)			=	0.010			
		H x S			=	0.016				H x S			=	0.014			
		H x S x T			=	0.015				H x S x T			=	0.012			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

4.2.4 Total sugars (%)

Table 12 shows the effect of harvest dates, postharvest treatments and storage periods on total sugars of “Red Delicious” apple under ambient conditions. A mean maximum total sugars of 10.26 per cent were observed in H₃ and minimum of 9.40 per cent in H₁ at 0 day of storage.

Postharvest treatments showed a significant effect on total sugars. Highest total sugars of 11.80, 12.57 and 13.03 per cent were observed in T₁, while T₅ recorded the lowest mean total sugars of 10.77, 11.17 and 11.69 per cent in three harvest dates H₁, H₂ and H₃, respectively.

During storage of 100 days under ambient conditions, there was significant increase in total sugars. Mean value of total sugars increased from 9.83 per cent at 0 day to 13.75 per cent after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on total sugars of “Red Delicious” apple under refrigerated conditions is presented in Table 12. Mean maximum total sugars of 10.26 per cent were observed in H₃ and minimum of 9.40 per cent in H₁ at 0 day of storage.

Among various treatments highest total sugars of 10.23, 10.65 and 11.03 per cent were observed in T₁, while T₅ recorded the lowest mean total sugars of 9.72, 9.99 and 10.38 per cent in three harvest dates H₁, H₂ and H₃, respectively and postharvest treatments showed a significant effect.

There was significant increase in total sugars during storage of 100 days under refrigerated conditions. Mean value of total sugars increased from 9.83 per cent at 0 day to 10.79 per cent after 100 days of storage.

4.2.5 Juice content (%)

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on juice content (%) of “Red Delicious” apple under ambient conditions is presented in Table 13. A mean maximum juice content of 59.50 per

Table-12 : Effect of harvest dates, post harvest treatments and storage conditions on total sugars (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	9.40	10.50	11.40	12.30	13.20	14.00	11.80	9.40	9.70	10.00	10.40	10.80	11.10	10.23
	T ₂	9.40	10.20	11.30	12.10	12.90	13.60	11.58	9.40	9.60	9.90	10.10	10.30	10.60	9.98
	T ₃	9.40	10.00	10.90	11.60	12.50	13.00	11.23	9.40	9.60	9.70	9.90	10.20	10.30	9.85
	T ₄	9.40	9.90	10.90	11.70	12.50	13.10	11.25	9.40	9.70	9.80	10.10	10.30	10.50	9.97
	T ₅	9.40	9.70	10.30	11.00	11.80	12.40	10.77	9.40	9.50	9.70	9.80	9.90	10.00	9.72
	Sub Mean	9.40	10.06	10.96	11.74	12.58	13.22	11.33	9.40	9.62	9.82	10.06	10.30	10.50	9.95
H ₂	T ₁	9.82	11.12	12.52	13.32	14.02	14.62	12.57	9.82	10.02	10.42	10.92	11.22	11.52	10.65
	T ₂	9.82	10.82	12.02	12.92	13.62	14.12	12.22	9.82	10.02	10.32	10.52	10.72	10.92	10.39
	T ₃	9.82	10.52	11.32	12.22	12.82	13.42	11.69	9.82	9.92	10.32	10.52	10.62	10.72	10.32
	T ₄	9.82	10.42	11.22	12.12	12.82	13.32	11.62	9.82	10.02	10.22	10.42	10.62	10.82	10.32
	T ₅	9.82	10.02	10.72	11.52	12.12	12.82	11.17	9.82	9.82	9.92	10.02	10.12	10.22	9.99
	Sub Mean	9.82	10.58	11.56	12.42	13.08	13.66	11.85	9.82	9.96	10.24	10.48	10.66	10.84	10.33
H ₃	T ₁	10.26	11.56	12.96	14.06	14.46	14.86	13.03	10.26	10.56	10.96	11.16	11.46	11.76	11.03
	T ₂	10.26	11.26	12.36	13.06	13.96	14.66	12.59	10.26	10.36	10.56	10.76	10.96	11.16	10.68
	T ₃	10.26	10.76	12.06	12.66	13.46	14.16	12.23	10.26	10.36	10.46	10.56	10.66	10.86	10.53
	T ₄	10.26	10.86	12.16	13.06	13.86	14.36	12.43	10.26	10.26	10.46	10.66	10.76	10.86	10.54
	T ₅	10.26	10.26	11.06	11.96	12.86	13.76	11.69	10.26	10.26	10.36	10.36	10.46	10.56	10.38
	Sub Mean	10.26	10.94	12.12	12.96	13.72	14.36	12.39	10.26	10.36	10.56	10.70	10.86	11.04	10.63
Grand Mean	9.83	10.53	11.55	12.37	13.13	13.75	11.86	9.83	9.98	10.21	10.41	10.61	10.79	10.30	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.213				Harvest (H) =			0.209			
		Treatment (T) =			0.207				Treatment (T) =			0.205			
		H x T =			0.114				H x T =			0.125			
		Storage (S) =			0.316				Storage (S) =			0.319			
		H x S =			0.322				H x S =			0.324			
		H x S x T =			0.221				H x S x T =			0.219			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-13 : Effect of harvest dates, post harvest treatments and storage conditions on juice content (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)							
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean	
H ₁	T ₁	59.20	58.10	52.60	50.20	42.00	37.30	49.90	59.20	58.60	56.80	52.80	50.60	49.00	54.50	
	T ₂	59.20	58.30	52.60	50.20	42.00	37.30	49.93	59.20	58.80	56.80	52.90	50.60	49.00	54.55	
	T ₃	59.20	58.70	52.80	50.40	42.20	37.50	50.13	59.20	58.80	57.00	53.00	50.80	49.20	54.67	
	T ₄	59.20	58.60	52.80	50.30	42.20	37.40	50.08	59.20	59.00	57.10	53.10	50.90	49.60	54.82	
	T ₅	59.20	58.80	52.90	50.40	42.30	37.60	50.20	59.20	59.00	57.10	53.10	51.60	49.70	54.87	
	Sub Mean	59.20	58.50	52.74	50.30	42.14	37.42	50.05	59.20	58.80	56.93	52.95	50.73	49.20	54.63	
H ₂	T ₁	59.50	58.50	82.40	50.50	42.40	37.30	50.10	59.50	59.30	57.30	53.60	51.40	50.10	55.20	
	T ₂	59.50	58.50	52.40	50.60	42.40	37.30	50.12	59.50	59.30	57.30	53.60	51.40	50.10	55.20	
	T ₃	59.50	59.00	52.50	50.70	42.60	37.50	50.30	59.50	59.40	57.50	53.70	51.60	50.30	55.33	
	T ₄	59.50	58.80	52.50	50.60	42.60	37.40	50.23	59.50	59.40	57.70	53.80	51.70	50.50	55.43	
	T ₅	59.50	59.00	52.50	50.80	42.70	37.50	50.33	59.50	59.40	57.70	53.80	51.70	50.80	55.48	
	Sub Mean	59.50	58.76	58.46	50.64	42.54	37.40	51.22	59.50	59.36	57.50	53.70	51.56	50.36	55.33	
H ₃	T ₁	59.20	58.40	52.30	49.40	41.50	36.80	49.60	59.20	58.60	56.70	53.10	50.70	48.90	54.53	
	T ₂	59.20	58.40	52.40	49.40	41.40	36.80	49.60	59.20	58.70	56.70	53.10	50.80	48.90	54.57	
	T ₃	59.20	58.70	52.60	49.60	41.70	37.00	49.80	59.20	58.70	56.80	53.20	50.80	49.00	54.62	
	T ₄	59.20	58.50	52.50	49.50	41.60	36.90	49.70	59.20	58.80	56.80	53.30	50.90	49.10	54.68	
	T ₅	59.20	58.70	52.60	49.60	41.70	37.00	49.80	59.20	58.80	56.80	53.40	50.90	49.10	54.70	
	Sub Mean	59.20	58.54	52.48	49.50	41.58	36.90	49.70	59.20	58.72	56.76	53.22	50.82	49.00	54.62	
Grand Mean		59.30	58.60	54.56	50.15	42.09	37.24	50.32	59.30	58.96	57.06	53.29	51.04	49.52	54.86	
CD (p≤0.05)							CD (p≤0.05)									
				Harvest (H)	=	0.319					Harvest (H)	=	0.309			
				Treatment (T)	=	0.121					Treatment (T)	=	0.113			
				H x T	=	0.425					H x T	=	0.428			
				Storage (S)	=	0.678					Storage (S)	=	0.648			
				H x S	=	0.679					H x S	=	0.667			
				H x S x T	=	0.546					H x S x T	=	0.532			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

cent was observed in H₂ and minimum of 59.20 per cent in H² and H₃ at 0 day of storage.

Postharvest treatments showed a significant effect on juice content. Highest juice content of 50.20, 50.33 and 49.80 per cent was observed for T₅ while as T₁ recorded the lowest mean juice content of 49.90, 50.10 and 49.60 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in juice content during storage of 100 days under ambient conditions. Mean value of juice content decreased from 59.30 per cent at 0 days to 37.24 per cent after 100 days of storage.

Data pertaining to effect of harvest dates, postharvest treatments and storage periods on juice content of “Red Delicious” apple under refrigerated conditions is presented in Table 13. A mean maximum juice content of 59.50 per cent was observed in H₂ and minimum of 49.20 per cent in H₁ and H₃ at 0 days of storage.

In three harvest dates H₁, H₂ and H₃, highest juice content of 54.87, 55.48 and 54.70 per cent was observed in T₅, while T₁ recorded the lowest mean juice content of 54.50, 55.20 and 54.53 per cent, respectively. Postharvest treatments showed a significant effect on juice content.

A significant decrease in juice content during storage of 100 days under ambient conditions was observed. Mean value of juice content decreased from 59.30 per cent at 0 days to 49.52 per cent after 100 days of storage.

4.2.6 Calcium content (mg/100g)

“Red Delicious” apples were stored under ambient conditions and effect of harvest dates, postharvest treatments and storage periods on calcium content was studied (Table 14). Mean maximum calcium of 6.90 per cent was observed in H₁ and minimum of 6.70 per cent in H₃ at 0 day of storage.

Postharvest treatments showed a significant effect on calcium content. Highest calcium of 7.05, 6.97 and 6.87 per cent was observed in T₅ while as T₁ recorded the lowest mean calcium content of 6.98, 6.92 and 6.82 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in total calcium during storage of 100 days under ambient conditions. Mean value of total calcium increased from 6.70 per cent at 0 days to 7.05 per cent after 100 days of storage.

Effect of harvest dates, postharvest treatments and storage periods on calcium of “Red Delicious” apple under refrigerated conditions was studied and is presented in Table 14. A mean maximum calcium of 6.90 per cent was observed in H₁ and minimum of 6.70 per cent in H₃ at 0 day of storage.

Among treatments, highest calcium of 7.03, 6.97 and 6.87 per cent was observed in T₅, while T₁ recorded the lowest mean calcium of 6.98, 6.95 and 6.85 per cent in three harvest dates H₁, H₂ and H₃, respectively and it varied significantly.

There was significant increase in calcium content during storage of 100 days under refrigerated conditions. Mean value of calcium content increased from 6.70 per cent at 0 day to 7.05 per cent after 100 days of storage.

4.2.7 Pectin content (%)

Pectin content of “Red Delicious” apple as affected by harvest dates, postharvest treatments and storage periods on under ambient conditions was studied and data is presented in Table 15. A mean maximum pectin content of 0.1.61 per cent was observed in H₁ and minimum of 1.38 per cent in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on pectin content. Highest pectin content of 1.23, 1.15 and 1.08 per cent was observed in T₅, while T₁ recorded the lowest mean pectin content of 1.10, 1.02 and 0.97 per cent in three harvest dates H₁, H₂ and H₃, respectively.

Table-14 : Effect of harvest dates, post harvest treatments and storage conditions on calcium content (mg/100 g) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	6.90	6.90	6.90	7.00	7.10	7.10	6.98	6.90	6.90	7.00	7.00	7.00	7.10	6.98
	T ₂	6.90	6.90	6.90	7.00	7.10	7.20	7.00	6.90	6.90	7.00	7.00	7.00	7.10	6.98
	T ₃	6.90	6.90	7.00	7.00	7.10	7.20	7.02	6.90	6.90	7.00	7.00	7.10	7.10	7.00
	T ₄	6.90	6.90	7.00	7.00	7.10	7.10	7.00	6.90	6.90	7.00	7.00	7.00	7.10	6.99
	T ₅	6.90	6.90	7.00	7.10	7.20	7.20	7.05	6.90	6.90	7.00	7.10	7.10	7.20	7.03
	Sub Mean	6.90	6.90	6.96	7.02	7.12	7.16	7.01	6.90	6.90	7.00	7.02	7.04	7.12	7.00
H ₂	T ₁	6.80	6.80	6.80	7.00	7.00	7.10	6.92	6.80	6.80	6.90	7.00	7.10	7.10	6.95
	T ₂	6.80	6.80	6.80	7.00	7.00	7.10	6.92	6.80	6.80	6.90	7.00	7.10	7.10	6.95
	T ₃	6.80	6.80	6.90	7.00	7.10	7.20	6.97	6.80	6.80	6.90	7.00	7.10	7.20	6.97
	T ₄	6.80	6.80	6.80	7.00	7.00	7.10	6.92	6.80	6.80	6.90	7.00	7.10	7.20	6.96
	T ₅	6.80	6.80	6.90	7.00	7.10	7.20	6.97	6.80	6.80	6.90	7.00	7.10	7.20	6.97
	Sub Mean	6.80	6.80	6.84	7.00	7.04	7.14	6.94	6.80	6.80	6.90	7.00	7.10	7.16	6.96
H ₃	T ₁	6.70	6.70	6.70	6.90	6.90	7.00	6.82	6.70	6.70	6.80	6.90	7.00	7.00	6.85
	T ₂	6.70	6.70	6.70	6.90	6.90	7.00	6.82	6.70	6.70	6.80	6.90	7.00	7.00	6.85
	T ₃	6.70	6.70	6.80	6.90	7.00	7.10	6.87	6.70	6.70	6.80	6.90	7.00	7.10	6.87
	T ₄	6.70	6.70	6.70	6.90	6.90	7.10	6.83	6.70	6.70	6.80	6.90	7.00	7.10	6.86
	T ₅	6.70	6.70	6.80	6.90	7.00	7.10	6.87	6.70	6.70	6.80	6.90	7.00	7.10	6.87
	Sub Mean	6.70	6.70	6.74	6.90	6.94	7.06	6.84	6.70	6.70	6.80	6.90	7.00	7.06	6.86
Grand Mean	6.70	6.70	6.72	6.90	6.92	7.05	6.83	6.70	6.70	6.80	6.90	7.00	7.05	6.86	
CD (p≤0.05)							CD (p≤0.05)								
Harvest (H) = 0.013							Harvest (H) = 0.015								
Treatment (T) = 0.005							Treatment (T) = 0.003								
H x T = 0.009							H x T = 0.009								
Storage (S) = 0.005							Storage (S) = 0.003								
H x S = 0.001							H x S = 0.004								
H x S x T = 0.008							H x S x T = 0.005								

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-15 : Effect of harvest dates, post harvest treatments and storage conditions on pectin content (%) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	1.61	1.38	1.08	1.01	0.91	0.61	1.10	1.61	1.51	1.47	1.34	1.11	0.92	1.33
	T ₂	1.61	1.39	1.13	1.03	0.99	0.63	1.13	1.61	1.53	1.48	1.35	1.13	0.94	1.34
	T ₃	1.61	1.58	1.18	1.07	1.01	0.71	1.19	1.61	1.55	1.51	1.37	1.17	0.97	1.36
	T ₄	1.61	1.41	1.15	1.05	1.00	0.68	1.15	1.61	1.54	1.49	1.36	1.16	0.98	1.36
	T ₅	1.61	1.59	1.31	1.10	1.01	0.74	1.23	1.61	1.56	1.52	1.41	1.22	0.99	1.39
	Sub Mean	1.61	1.47	1.17	1.05	0.98	0.67	1.16	1.61	1.54	1.49	1.37	1.16	0.96	1.35
H ₂	T ₁	1.49	1.24	1.00	0.97	0.86	0.54	1.02	1.49	1.41	1.37	1.27	1.10	0.92	1.26
	T ₂	1.49	1.29	1.06	0.99	0.89	0.59	1.05	1.49	1.42	1.38	1.28	1.12	0.95	1.27
	T ₃	1.49	1.34	1.09	1.04	0.98	0.67	1.10	1.49	1.44	1.40	1.32	1.17	0.98	1.30
	T ₄	1.49	1.32	1.08	1.00	0.95	0.61	1.08	1.49	1.44	1.39	1.30	1.14	0.96	1.29
	T ₅	1.49	1.41	1.13	1.09	0.99	0.79	1.15	1.49	1.45	1.41	1.34	1.19	0.99	1.31
	Sub Mean	1.49	1.32	1.07	1.02	0.93	0.64	1.08	1.49	1.43	1.39	1.30	1.14	0.96	1.29
H ₃	T ₁	1.38	1.19	0.97	0.94	0.83	0.49	0.97	1.38	1.30	1.18	1.06	0.94	0.88	1.12
	T ₂	1.38	1.24	0.98	0.96	0.87	0.56	1.00	1.38	1.32	1.20	1.08	0.94	0.89	1.14
	T ₃	1.38	1.29	1.28	0.98	0.98	0.58	1.08	1.38	1.35	1.23	1.13	0.97	0.91	1.16
	T ₄	1.38	1.31	1.06	1.03	0.96	0.63	1.06	1.38	1.34	1.23	1.11	0.95	0.89	1.15
	T ₅	1.38	1.33	1.08	1.06	0.97	0.68	1.08	1.38	1.36	1.26	1.16	0.98	0.93	1.18
	Sub Mean	1.38	1.27	1.07	0.99	0.92	0.59	1.04	1.38	1.33	1.22	1.11	0.96	0.90	1.15
Grand Mean	1.38	1.29	1.08	1.02	0.92	0.62	2.02	1.38	1.34	1.24	1.13	0.97	0.91	1.16	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			=	0.028			Harvest (H)			=	0.03		
		Treatment (T)			=	0.038			Treatment (T)			=	0.048		
		H x T			=	0.110			H x T			=	0.112		
		Storage (S)			=	0.105			Storage (S)			=	0.101		
		H x S			=	0.092			H x S			=	0.103		
		H x S x T			=	0.114			H x S x T			=	0.111		

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

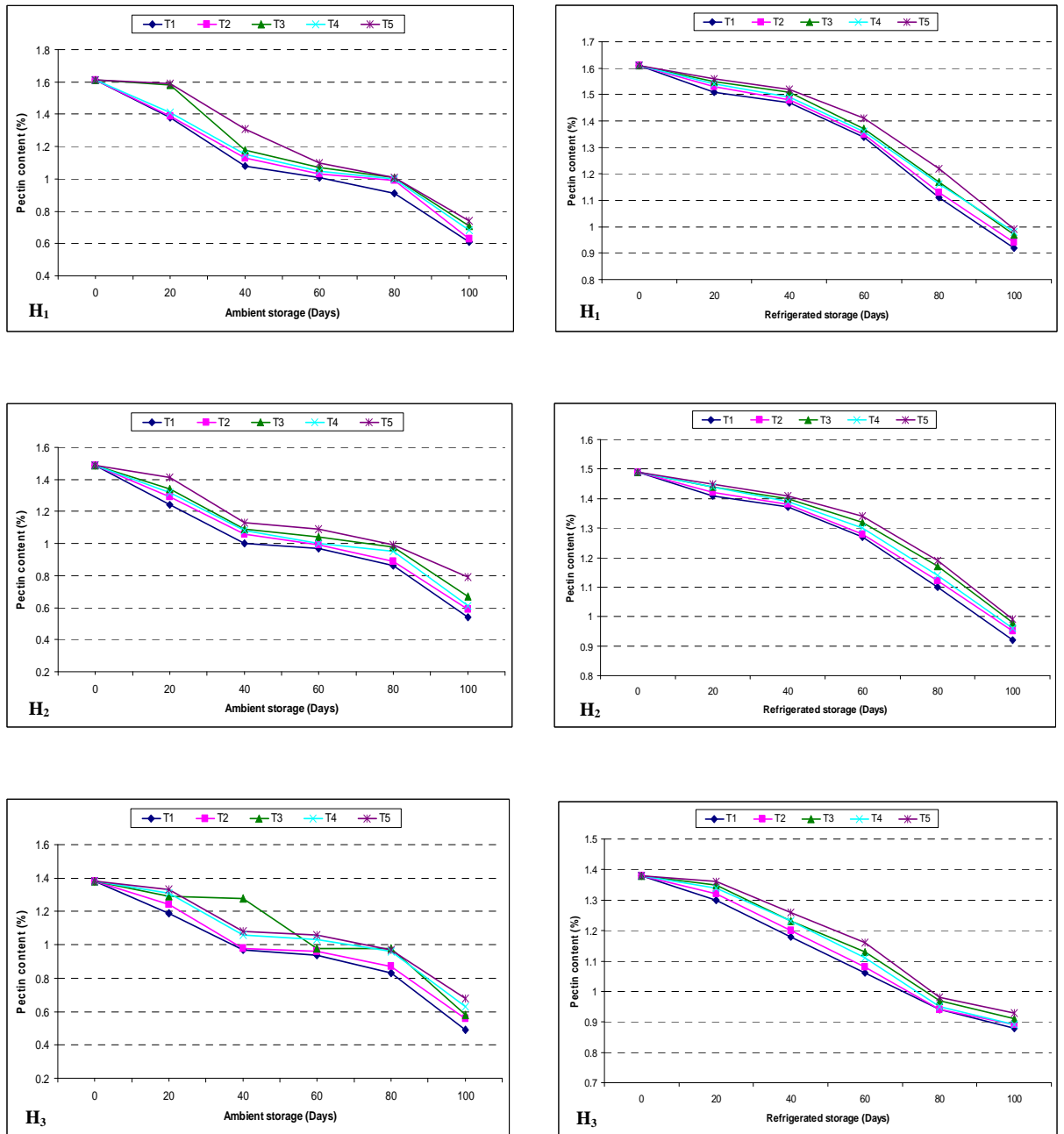


Fig. 4 : Effect of harvest dates, post harvest treatments and storage conditions on pectin content (%) of apple

Mean value of pectin content decreased from 1.38 per cent at 0 day to 0.62 per cent after 100 days of storage under ambient conditions. There was significant decrease in pectin content during storage of 100 days.

Table 15 shows data pertaining to the effect of harvest dates, postharvest treatments and storage periods on pectin content of “Red Delicious” apple under refrigerated conditions. A mean maximum pectin content of 0.1.61 per cent was observed in H₁ and minimum of 1.38 per cent in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on pectin content. Highest pectin content of 1.39, 1.31 and 1.18 per cent was observed in T₅, while T₁ recorded the lowest mean pectin content of 1.33, 1.26 and 1.12 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in pectin content during storage of 100 days under ambient conditions. Mean values of pectin content decreased from 1.38 per cent at 0 day to 0.91 per cent after 100 days of storage.

4.2.8 Anthocyanin (mg/100g)

Table 16 shows data pertaining to the effect of harvest dates, postharvest treatments and storage periods on anthocyanin content of “Red Delicious” apple under ambient conditions. A mean maximum anthocyanin content of 33.30 mg/100g was observed in H₃ and minimum of 30.30 mg/100g in H₁ at 0 day of storage.

A significant effect of postharvest treatments on anthocyanin content was observed. Highest anthocyanin content of 29.98, 31.52 and 31.88 mg/100g was observed in T₅, while T₁ recorded the lowest mean anthocyanin content of 29.87, 31.38 and 31.68 mg/100g in three harvest dates H₁, H₂ & H₃, respectively.

Total anthocyanin content significantly increased during storage of 100 days under ambient conditions. Mean value of total anthocyanin content increased from 31.93 mg/100g at 0 day to 28.05 mg/100g after 100 days of storage.

Table-16 : Effect of harvest dates, post harvest treatments and storage conditions on anthocyanin (mg/100 g) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	30.30	31.80	31.30	30.00	28.40	27.40	29.87	30.30	30.90	31.60	30.30	29.90	28.30	30.22
	T ₂	30.30	31.60	31.10	30.20	28.60	28.00	29.97	30.30	30.80	31.50	30.50	29.50	28.80	30.23
	T ₃	30.30	31.30	31.00	30.30	28.80	28.20	29.98	30.30	30.50	31.40	30.80	29.70	28.90	30.27
	T ₄	30.30	31.80	31.30	30.00	28.60	27.90	29.98	30.30	30.50	31.40	30.60	29.80	29.00	30.27
	T ₅	30.30	31.10	31.00	30.30	28.80	28.20	29.95	30.30	30.70	31.50	30.80	29.50	28.90	30.28
	Sub Mean	30.30	31.52	31.14	30.16	28.64	27.94	29.95	30.30	30.68	31.48	30.60	29.68	28.78	30.25
H ₂	T ₁	32.20	33.60	33.20	31.70	29.80	27.80	31.38	32.20	32.70	32.90	31.70	30.20	29.10	31.47
	T ₂	32.20	33.60	33.10	31.90	29.80	27.80	31.40	32.20	32.70	32.90	31.90	30.60	29.20	31.58
	T ₃	32.20	33.20	33.20	32.10	30.10	28.12	31.49	32.20	32.50	32.70	32.10	30.70	29.50	31.62
	T ₄	32.20	33.50	33.10	31.90	29.80	27.90	31.40	32.20	32.60	32.80	31.90	30.60	29.60	31.62
	T ₅	32.20	33.10	32.70	32.30	30.10	28.70	31.52	32.20	32.50	32.70	32.10	30.70	29.70	31.65
	Sub Mean	32.20	33.40	33.06	26.38	29.92	28.06	30.50	32.20	32.60	32.80	31.94	30.56	29.42	31.59
H ₃	T ₁	33.30	34.20	32.60	31.30	30.30	28.40	31.68	33.30	34.20	34.30	32.50	30.60	29.70	32.43
	T ₂	33.30	34.30	32.80	31.50	30.20	28.30	31.73	33.30	34.10	34.20	32.70	30.60	29.80	32.45
	T ₃	33.30	34.70	33.30	32.00	29.90	28.10	31.88	33.30	33.80	34.10	32.90	30.90	30.10	32.52
	T ₄	33.30	34.50	33.20	31.90	30.00	28.10	31.83	33.30	33.90	34.10	32.70	30.80	30.00	32.47
	T ₅	33.30	34.90	33.40	32.20	29.50	27.90	31.87	33.30	33.80	33.80	33.10	31.00	30.10	32.52
	Sub Mean	33.30	34.52	33.06	31.78	29.98	28.16	31.80	33.30	33.96	34.10	32.78	30.78	29.94	32.48
Grand Mean	31.93	33.15	32.42	29.44	29.51	28.05	30.75	31.93	32.41	32.79	31.77	30.34	29.38	31.44	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.204				Harvest (H) =			0.194			
		Treatment (T) =			0.247				Treatment (T) =			0.239			
		H x T =			0.214				H x T =			0.214			
		Storage (S) =			0.305				Storage (S) =			0.310			
		H x S =			0.313				H x S =			0.313			
		H x S x T =			0.226				H x S x T =			0.217			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

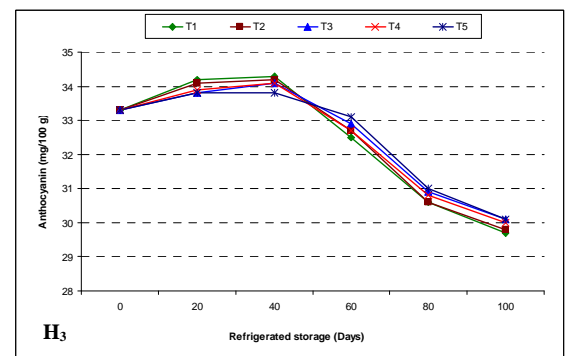
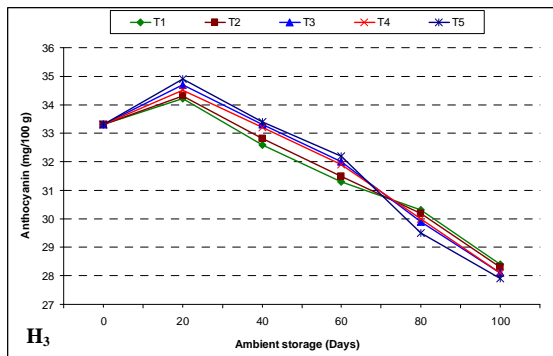
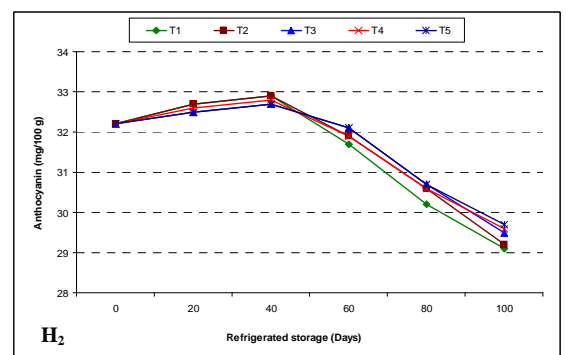
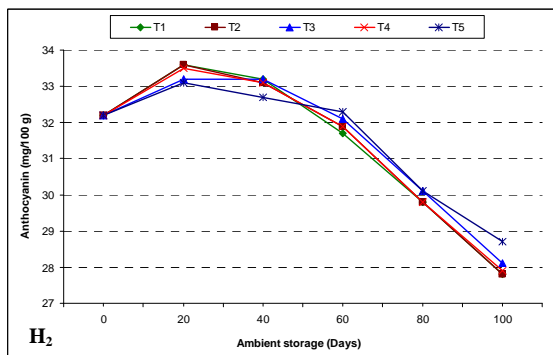
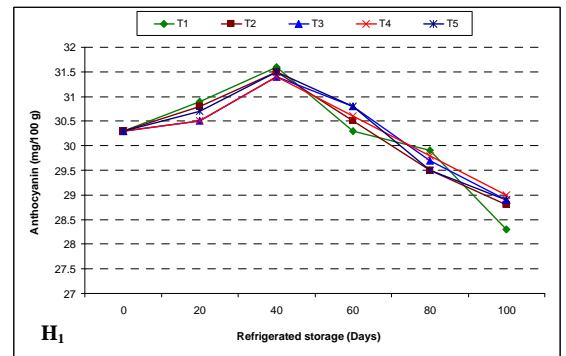
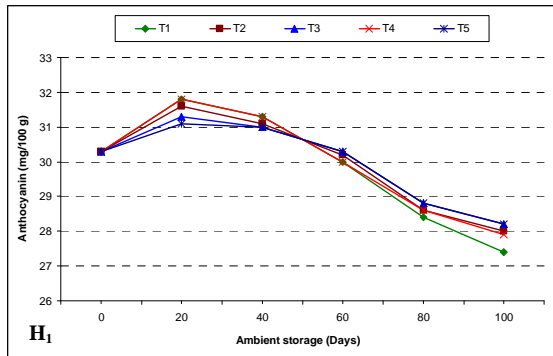


Fig. 5 : Effect of harvest dates, post harvest treatments and storage conditions on anthocyanin (mg/100 g) of apple

Effect of harvest dates, postharvest treatments and storage periods on anthocyanin content of “Red Delicious” apple under refrigerated conditions is presented in Table 16. A mean maximum anthocyanin content of 30.30 mg/100g was observed in H₁ and minimum of 33.30 mg/100g in H₃ at 0 day of storage.

Highest anthocyanin content of 30.28, 31.65 and 32.52 mg/100g was observed in T₅, while T₁ recorded the lowest mean anthocyanin content of 30.22, 31.47 and 32.43 mg/100g in three harvest dates H₁, H₂ and H₃ respectively and varied significantly among treatments.

Anthocyanin content significantly increased during storage of 100 days under refrigerated conditions. Mean value of anthocyanin content increased from 31.93 mg/100g at 0 day to 29.38 mg/100g after 100 days of storage.

4.2.9 Ascorbic acid (mg/100g)

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on ascorbic acid of “Red Delicious” apple under ambient conditions is presented in Table 17. A mean maximum ascorbic acid of 12.50 mg/100g was observed in H₃ and minimum of 11.90 mg/100g in H₁ at 0 days of storage.

Ascorbic acid varies significantly in different postharvest treatments. Highest ascorbic acid of 9.20, 9.47 and 9.48 mg/100g was observed for T₅ while as T₁ recorded the lowest mean ascorbic acid of 8.92, 9.18 and 9.22 mg/100g in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in ascorbic acid during storage of 100 days under ambient conditions. Mean value of ascorbic acid decreased from 12.27 mg/100g at 0 day to 4.47 mg/100g after 100 days of storage.

At 0 day of storage, a mean maximum ascorbic acid of 12.50 mg/100g was observed in H₃ and minimum of 11.90 mg/100g in H₃ under refrigerated conditions (Table 17).

Table-17 : Effect of harvest dates, post harvest treatments and storage conditions on ascorbic acid (mg/100 g) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	11.90	11.10	10.10	9.20	7.00	4.20	8.92	11.90	11.40	11.00	10.30	9.80	8.10	10.42
	T ₂	11.90	11.20	10.10	9.30	7.10	4.20	8.97	11.90	11.40	11.10	10.30	9.90	8.20	10.47
	T ₃	11.90	11.50	10.40	9.40	7.20	4.40	9.13	11.90	11.60	11.40	10.50	10.20	8.60	10.70
	T ₄	11.90	11.30	10.30	9.30	7.10	4.30	9.03	11.90	11.50	11.20	10.40	10.00	8.50	10.58
	T ₅	11.90	11.60	10.50	9.40	7.30	4.50	9.20	11.90	11.70	11.50	10.50	10.20	8.60	10.73
	Sub Mean	11.90	11.34	10.28	9.32	7.14	4.32	9.05	11.90	11.52	11.24	10.40	10.02	8.40	10.58
H ₂	T ₁	12.40	11.70	10.50	9.00	7.00	4.50	9.18	12.40	12.10	11.50	10.40	10.00	8.80	10.87
	T ₂	12.40	11.80	10.60	9.10	7.10	4.60	9.27	12.40	12.20	11.50	10.40	10.10	8.90	10.92
	T ₃	12.40	11.90	10.70	9.30	7.30	4.70	9.38	12.40	12.30	11.80	10.60	10.30	9.20	11.10
	T ₄	12.40	11.90	10.60	9.20	7.20	4.80	9.35	12.40	12.20	11.70	10.50	10.20	9.30	11.05
	T ₅	12.40	12.00	10.90	9.30	7.40	4.80	9.47	12.40	12.30	11.80	10.70	10.40	9.40	11.17
	Sub Mean	12.40	11.86	10.66	9.18	7.20	4.68	9.33	12.40	12.22	11.66	10.52	10.20	9.12	11.02
H ₃	T ₁	12.50	11.90	10.40	9.10	7.10	4.30	9.22	12.50	12.00	11.30	10.20	9.70	8.30	10.67
	T ₂	12.50	12.00	10.40	9.30	7.20	4.30	9.28	12.50	12.10	11.40	10.20	9.80	8.40	10.73
	T ₃	12.50	12.20	10.60	9.40	7.30	4.50	9.42	12.50	12.20	11.60	10.50	9.90	8.70	10.90
	T ₄	12.50	12.10	10.50	9.30	7.20	4.40	9.33	12.50	12.10	11.50	10.30	9.80	8.50	10.78
	T ₅	12.50	12.20	10.70	9.50	7.40	4.60	9.48	12.50	12.30	11.70	10.60	10.10	8.90	11.02
	Sub Mean	12.50	12.08	10.52	9.32	7.24	4.42	9.35	12.50	12.14	11.50	10.36	9.86	8.56	10.82
Grand Mean		12.27	11.76	10.49	9.27	7.19	4.47	9.24	12.27	11.96	11.47	10.43	10.03	8.69	10.81
		CD (p=0.05)							CD (p=0.05)						
		Harvest (H) =			0.210				Harvest (H) =			0.201			
		Treatment (T) =			0.110				Treatment (T) =			0.113			
		H x T =			0.107				H x T =			0.101			
		Storage (S) =			0.227				Storage (S) =			0.229			
		H x S =			0.209				H x S =			0.204			
		H x S x T =			0.221				H x S x T =			0.220			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

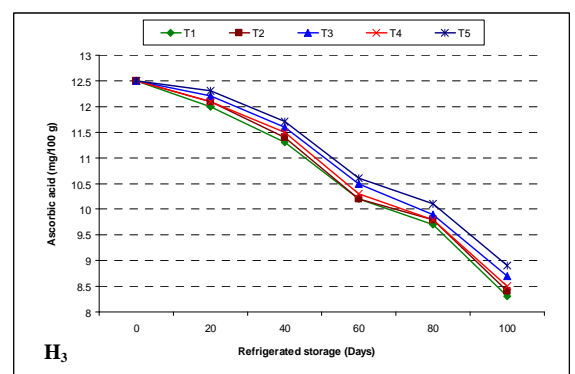
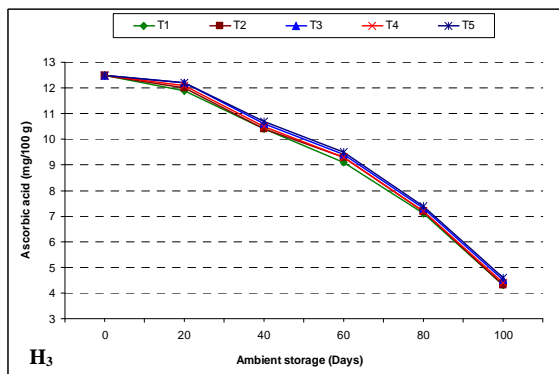
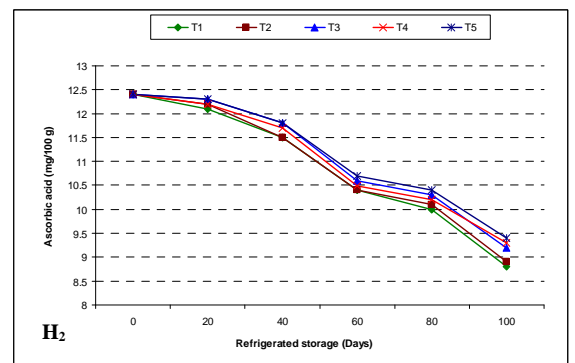
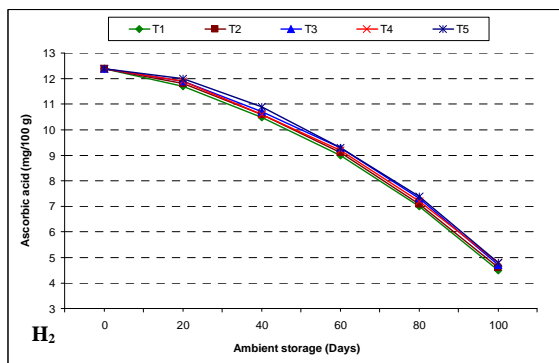
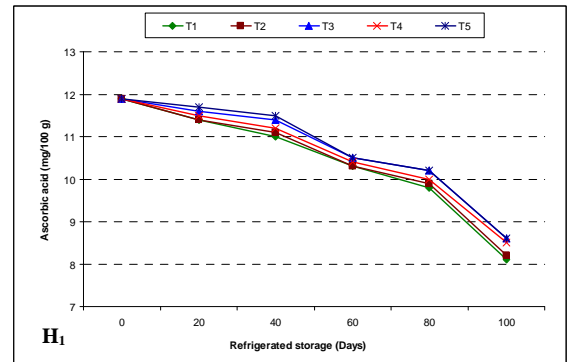
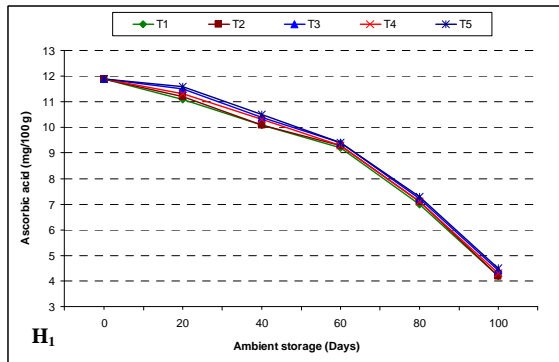


Fig. 6 : Effect of harvest dates, post harvest treatments and storage conditions on ascorbic acid (mg/100 g) of apple

Postharvest treatments showed a significant effect on ascorbic acid. Highest ascorbic acid of 10.73, 11.17 and 11.02 mg/100g was observed in T₅, while T₁ recorded the lowest mean ascorbic acid of 10.42, 10.87 and 10.67 mg/100g in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in ascorbic acid during storage of 100 days under refrigerated conditions. Mean value of ascorbic acid decreased from 12.27 mg/100g at 0 day to 8.69 mg/100g after 100 days of storage.

4.2.10 Polyphenols (mg/100g)

Under ambient conditions, effect of harvest dates, postharvest treatments and storage periods on polyphenols of “Red Delicious” apple was studied and data is presented in Table 18. A mean maximum polyphenols of 2.80 mg/100g was observed in H₁ and minimum of 2.66 mg/100g in H₃ at 0 days of storage.

T₅ recorded highest polyphenols of 2.65, 2.55 and 2.58 mg/100g while as T₁ recorded the lowest mean of polyphenols 2.60, 2.48 and 2.49 mg/100g in three harvest dates H₁, H₂ and H₃, respectively. Postharvest treatments showed a significant effect on polyphenols.

A significant decrease in polyphenols during storage of 100 days under ambient conditions was observed. Mean value of polyphenols decreased from 2.70 mg/100g at 0 days to 2.42 mg/100g after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on polyphenols of “Red Delicious” apple under refrigerated conditions is presented in Table 18. A mean maximum polyphenols of 2.80 mg/100g was observed in H₁ and minimum of 2.66 mg/100g in H₃ at 0 days of storage.

Postharvest treatments showed a significant effect on polyphenols. Highest polyphenols of 2.77, 2.65 and 2.66 mg/100 g was observed in T₅, while T₁ recorded the lowest mean polyphenols of 2.70, 2.53 and 2.54 mg/100 g in three harvest dates H₁, H₂ and H₃, respectively.

Table-18 : Effect of harvest dates, post harvest treatments and storage conditions on polyphenols (mg/100 g) of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	2.80	2.80	2.60	2.50	2.50	2.40	2.60	2.80	2.80	2.70	2.70	2.60	2.60	2.70
	T ₂	2.80	2.80	2.70	2.60	2.50	2.50	2.60	2.80	2.80	2.70	2.70	2.60	2.60	2.70
	T ₃	2.80	2.80	2.70	2.60	2.50	2.20	2.65	2.80	2.80	2.80	2.80	2.70	2.70	2.77
	T ₄	2.80	2.80	2.70	2.60	2.50	2.50	2.65	2.80	2.80	2.80	2.80	2.70	2.70	2.77
	T ₅	2.80	2.80	2.70	2.60	2.50	2.50	2.65	2.80	2.80	2.80	2.80	2.70	2.70	2.77
	Sub Mean	2.80	2.80	2.68	2.58	2.50	2.42	2.63	2.80	2.80	2.76	2.76	2.66	2.66	2.74
H ₂	T ₁	2.65	2.65	2.45	2.45	2.35	2.35	2.48	2.65	2.65	2.55	2.45	2.45	2.45	2.53
	T ₂	2.65	2.65	2.45	2.55	2.35	2.35	2.50	2.65	2.65	2.65	2.55	2.55	2.55	2.60
	T ₃	2.65	2.65	2.55	2.55	2.45	2.45	2.55	2.65	2.65	2.65	2.65	2.65	2.65	2.65
	T ₄	2.65	2.65	2.55	2.55	2.45	2.45	2.55	2.65	2.65	2.65	2.65	2.55	2.55	2.62
	T ₅	2.65	2.65	2.55	2.55	2.45	2.45	2.55	2.65	2.65	2.65	2.65	2.65	2.65	2.65
	Sub Mean	2.65	2.65	2.51	2.53	2.41	2.41	2.53	2.65	2.65	2.63	2.59	2.57	2.57	2.61
H ₃	T ₁	2.66	2.66	2.46	2.46	2.36	2.36	2.49	2.66	2.66	2.56	2.46	2.46	2.46	2.54
	T ₂	2.66	2.66	2.56	2.56	2.46	2.46	2.56	2.66	2.66	2.66	2.56	2.60	2.56	2.62
	T ₃	2.66	2.66	2.56	2.56	2.56	2.46	2.58	2.66	2.66	2.66	2.66	2.66	2.66	2.66
	T ₄	2.66	2.66	2.56	2.56	2.56	2.46	2.57	2.66	2.66	2.66	2.66	2.66	2.56	2.64
	T ₅	2.66	2.66	2.56	2.56	2.56	2.46	2.58	2.66	2.66	2.66	2.66	2.66	2.66	2.66
	Sub Mean	2.66	2.66	2.54	2.54	2.50	2.44	2.56	2.66	2.66	2.64	2.60	2.61	2.58	2.62
Grand Mean	2.70	2.70	2.58	2.55	2.47	2.42	2.57	2.70	2.70	2.68	2.65	2.61	2.60	2.66	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			= 0.004				Harvest (H)			= 0.003			
		Treatment (T)			= 0.001				Treatment (T)			= 0.001			
		H x T			= 0.004				H x T			= 0.003			
		Storage (S)			= 0.002				Storage (S)			= 0.001			
		H x S			= 0.005				H x S			= 0.002			
		H x S x T			= 0.003				H x S x T			= 0.004			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Polyphenols decreased significantly from 0.2.70 mg/100g at 0 days to 2.60 mg/100g after 100 days of storage under refrigerated conditions.

4.2.11 Pectin methyl esterase activity (MeOH equivalent) [$\mu\text{mole/litre/day}$]

During study, a mean maximum pectin methyl esterase of 31.27 $\mu\text{mole/litre/day}$ was observed in H₃ and minimum of 29.47 $\mu\text{mole/litre/day}$ in H₁ at 0 day of storage (Table 19).

Postharvest treatments showed a significant effect on pectin methyl esterase. Highest pectin methyl esterase of 40.47, 40.79 and 42.17 $\mu\text{mole/litre/day}$ was observed in T₁, while T₅ recorded the lowest mean pectin methyl esterase of 38.54, 39.84 and 41.35 $\mu\text{mole/litre/day}$ in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in pectin methyl esterase during storage of 100 days under ambient conditions. Mean value of pectin methyl esterase increased from 30.32 $\mu\text{mole/litre/day}$ at 0 day to 49.43 $\mu\text{mole/litre/day}$ after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on pectin methyl esterase of “Red Delicious” apple under refrigerated conditions is presented in Table 19. A mean maximum pectin methyl esterase of 31.27 $\mu\text{mole/litre/day}$ was observed in H₃ and minimum of 29.47 $\mu\text{mole/litre/day}$ in H₁ at 0 day of storage.

In three harvest dates H₁, H₂ and H₃ highest pectin methyl esterase of 32.30, 32.44 and 33.60 $\mu\text{mole/litre/day}$ was recorded for T₁ while as T₅ recorded the lowest mean pectin methyl esterase of 31.50, 31.79 and 32.84 $\mu\text{mole/litre/day}$ respectively. It was observed that postharvest treatments had a significant effect on pectin methyl esterase activity.

Pectin methyl esterase significantly increased during storage of 100 days under refrigerated conditions. Mean value of pectin methyl esterase increased from 30.32 $\mu\text{mole/litre/day}$ at 0 day to 34.81 $\mu\text{mole/litre/day}$ after 100 days of storage.

Table-19 : Effect of harvest dates, post harvest treatments and storage conditions on pectin methyl esterase (MeOH equivalent) [μ mole/litre/day] of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	29.47	33.47	38.27	44.27	47.17	50.17	40.47	29.47	30.27	31.57	33.27	34.07	35.17	32.30
	T ₂	29.47	33.17	37.97	43.87	46.97	49.87	40.22	29.47	30.07	31.37	32.97	33.87	34.97	32.12
	T ₃	29.47	32.87	36.67	42.07	44.67	47.27	38.84	29.47	29.87	31.07	32.47	33.37	34.27	31.75
	T ₄	29.47	33.07	37.07	43.17	45.17	48.17	39.35	29.47	30.17	31.27	32.87	33.67	34.47	31.99
	T ₅	29.47	32.67	36.27	41.77	44.17	46.87	38.54	29.47	29.77	30.87	32.07	32.97	33.87	31.50
	Sub Mean	29.47	33.05	37.25	43.03	45.63	48.47	39.48	29.47	30.03	31.23	32.73	33.59	34.55	31.93
H ₂	T ₁	30.22	34.02	39.02	44.62	47.22	49.62	40.79	30.22	31.12	31.72	33.02	33.72	34.82	32.44
	T ₂	30.22	33.82	38.62	44.02	47.02	49.42	40.52	30.22	30.92	31.52	32.82	33.42	34.52	32.24
	T ₃	30.22	33.62	38.32	43.82	46.62	48.42	40.17	30.22	30.82	31.22	32.62	33.22	34.02	32.02
	T ₄	30.22	33.42	38.42	44.42	47.22	49.02	40.45	30.22	31.02	31.42	33.02	33.52	34.22	32.24
	T ₅	30.22	33.22	38.02	43.62	46.12	47.82	39.84	30.22	30.62	31.02	32.32	32.82	33.72	31.79
	Sub Mean	30.22	33.62	38.48	44.10	46.84	48.86	40.35	30.22	30.90	31.38	32.76	33.34	34.26	32.14
H ₃	T ₁	31.27	35.37	39.27	46.57	49.17	51.37	42.17	31.27	32.37	33.27	33.97	34.77	35.97	33.60
	T ₂	31.27	35.07	39.07	46.37	48.97	51.17	41.99	31.27	32.07	33.07	33.77	34.57	35.87	33.44
	T ₃	31.27	34.87	38.77	46.07	48.57	50.77	41.72	31.27	31.77	32.57	33.37	33.97	35.57	33.09
	T ₄	31.27	35.27	38.97	46.27	48.77	51.07	41.94	31.27	31.87	32.77	33.67	34.27	35.77	33.27
	T ₅	31.27	34.77	38.37	45.37	47.97	50.37	41.35	31.27	31.57	32.37	33.17	33.67	34.97	32.84
	Sub Mean	31.27	35.07	38.89	46.13	48.69	50.95	41.83	31.27	31.93	32.81	33.59	34.25	35.63	33.25
Grand Mean		30.32	33.91	38.21	44.42	47.05	49.43	40.56	30.32	30.95	31.81	33.03	33.73	34.81	32.44
CD (p \leq 0.05)							CD (p \leq 0.05)								
Harvest (H) = 0.78							Harvest (H) = 0.73								
Treatment (T) = 0.42							Treatment (T) = 0.38								
H x T = 1.02							H x T = 1.05								
Storage (S) = 1.09							Storage (S) = 1.06								
H x S = 1.06							H x S = 1.08								
H x S x T = 1.112							H x S x T = 1.110								

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

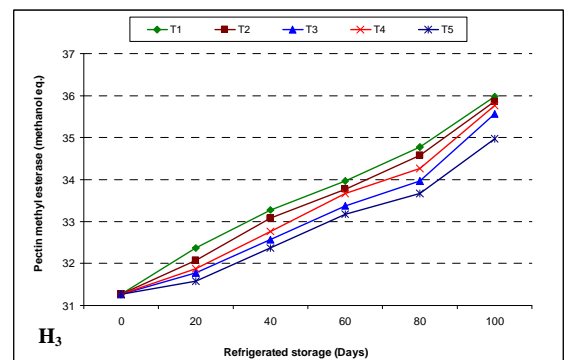
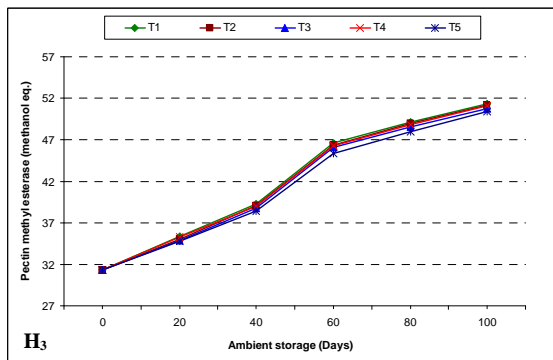
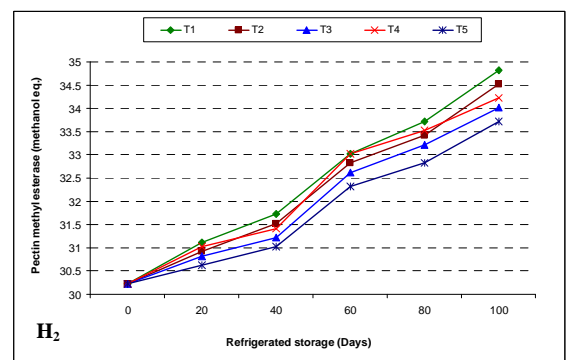
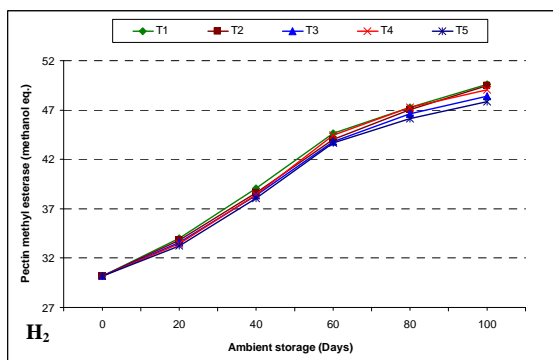
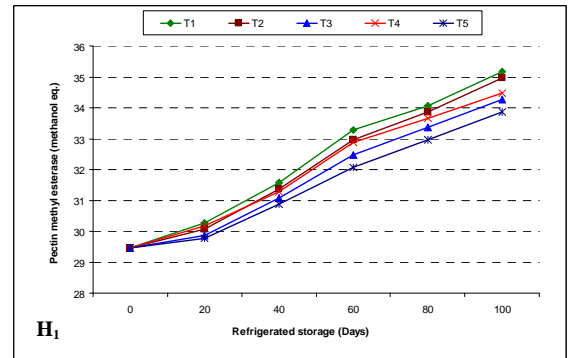
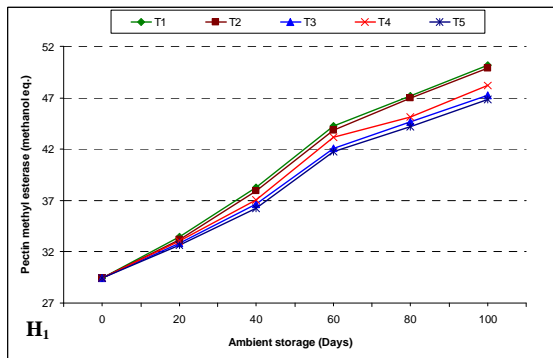


Fig. 7 : Effect of harvest dates, post harvest treatments and storage conditions on pectin methyl esterase ($\mu\text{m}/\text{litre}/\text{hour}$) activity of apple

4.2.12 Polygalacturonase activity (% loss in viscosity)

Polygalacturonase activity of “Red Delicious” apple under ambient conditions is presented in Table 20. Effect of harvest dates, postharvest treatments and storage periods was studied. A mean maximum polygalacturonase activity of 10.20 per cent was observed in H₃ and minimum of 8.60 per cent in H₁ at 0 days of storage.

Postharvest treatments showed a significant effect on polygalacturonase activity. Highest polygalacturonase activity of 12.60, 13.07 and 14.25 per cent was observed in T₁, while T₅ recorded the lowest mean polygalacturonase activity of 10.98, 11.78 and 13.43 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in polygalacturonase activity during storage of 100 days under ambient conditions. Mean value of polygalacturonase activity increased from 9.33 per cent at 0 day to 18.23 per cent after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on polygalacturonase activity of “Red Delicious” apples under refrigerated conditions is presented in Table 20. A mean maximum polygalacturonase activity of 10.20 per cent was observed in H₃ and minimum of 8.60 per cent in H₁ at 0 day of storage.

Among different postharvest treatments, highest polygalacturonase activity of 11.60, 11.73 and 12.57 per cent was observed in T₁, while T₅ recorded the lowest mean polygalacturonase activity of 31.50, 31.79 and 32.84 per cent in three harvest dates H₁, H₂ and H₃, respectively.

There was significant increase in polygalacturonase activity during storage of 100 days under refrigerated conditions. Mean value of polygalacturonase activity increased from 9.39 per cent at 0 day to 14.90 per cent after 100 days of storage.

Table-20 : Effect of harvest dates, post harvest treatments and storage conditions on polygalactouronase activity (% loss in viscosity) activity of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	8.60	9.20	10.70	12.30	15.60	19.20	12.60	8.90	9.60	10.50	12.00	13.30	15.30	11.60
	T ₂	8.60	8.90	10.30	11.60	15.00	18.50	12.15	8.90	9.40	10.30	11.80	13.10	15.00	11.42
	T ₃	8.60	8.70	9.40	10.20	13.80	16.60	11.22	8.70	8.90	10.00	11.50	11.70	14.20	10.83
	T ₄	8.60	8.90	10.00	11.10	14.60	17.90	11.85	8.80	9.30	10.10	11.70	12.20	14.90	11.17
	T ₅	8.60	8.60	9.20	10.00	13.30	16.20	10.98	8.60	8.80	9.60	11.00	11.20	14.10	10.55
	Sub Mean	8.60	8.86	9.92	11.04	14.46	17.68	11.76	8.78	9.20	10.10	11.60	12.30	14.70	11.11
H ₂	T ₁	9.20	10.50	11.80	12.80	15.20	18.90	13.07	9.20	9.80	10.80	11.60	13.50	15.50	11.73
	T ₂	9.20	10.30	11.60	12.50	15.00	18.20	12.80	9.20	9.80	10.60	11.50	13.30	15.10	11.58
	T ₃	9.20	10.00	11.20	12.10	14.20	16.20	12.15	9.20	9.50	10.20	11.00	13.00	14.00	11.15
	T ₄	9.20	10.30	11.50	12.50	14.60	17.10	12.53	9.20	9.70	10.50	11.50	13.20	14.10	11.37
	T ₅	9.20	10.10	11.00	12.00	12.80	15.60	11.78	9.20	9.40	10.00	10.80	12.80	13.60	10.97
	Sub Mean	9.20	10.24	11.42	12.38	14.36	17.20	12.47	9.20	9.64	10.42	11.28	13.16	14.46	11.36
H ₃	T ₁	10.20	11.80	12.50	14.10	16.50	20.40	14.25	10.20	12.00	11.80	13.30	14.00	16.10	12.57
	T ₂	10.20	11.40	12.30	13.80	16.20	20.00	13.98	10.20	11.00	11.70	13.10	13.80	15.90	12.62
	T ₃	10.20	11.10	12.00	13.10	15.80	19.10	13.55	10.20	10.50	11.30	12.60	13.40	15.20	12.20
	T ₄	10.20	11.30	12.20	13.50	16.00	19.70	13.82	10.20	10.80	11.50	12.90	13.60	15.50	12.42
	T ₅	10.20	11.00	12.10	13.20	15.70	18.40	13.43	10.20	10.40	11.00	12.50	13.20	15.00	12.05
	Sub Mean	10.20	11.32	12.22	13.54	16.04	19.52	13.81	10.20	30.94	11.46	12.88	13.60	15.54	15.77
Grand Mean	9.33	10.14	11.19	12.32	14.95	18.13	12.68	9.39	16.59	10.66	11.92	13.02	14.90	12.75	
		CD (p=0.05)							CD (p=0.05)						
		Harvest (H) =			0.95				Harvest (H) =			0.93			
		Treatment (T) =			0.71				Treatment (T) =			0.79			
		H x T =			0.82				H x T =			0.83			
		Storage (S) =			1.01				Storage (S) =			1.04			
		H x S =			1.04				H x S =			1.00			
		H x S x T =			1.03				H x S x T =			1.07			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

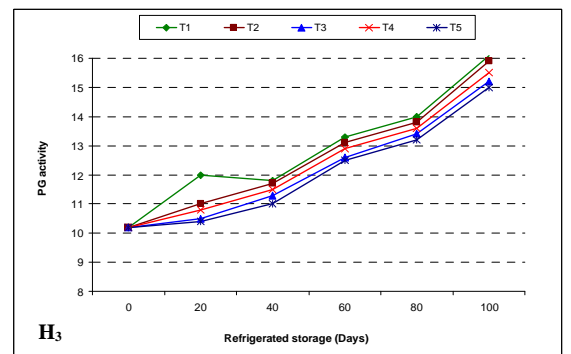
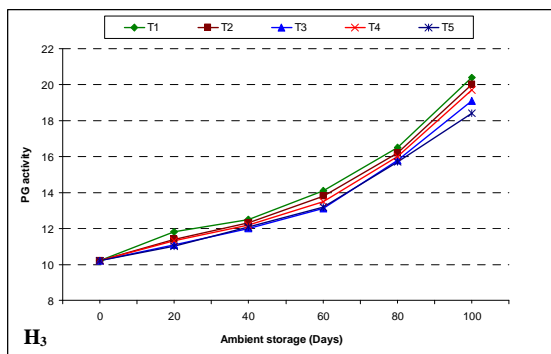
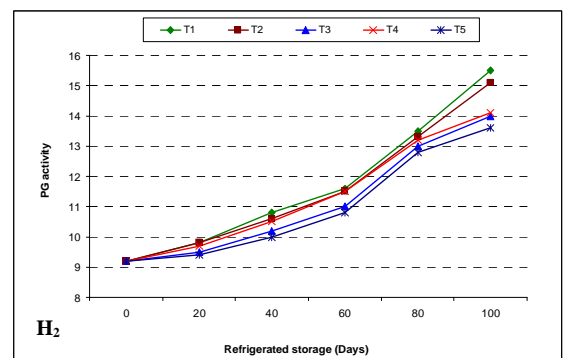
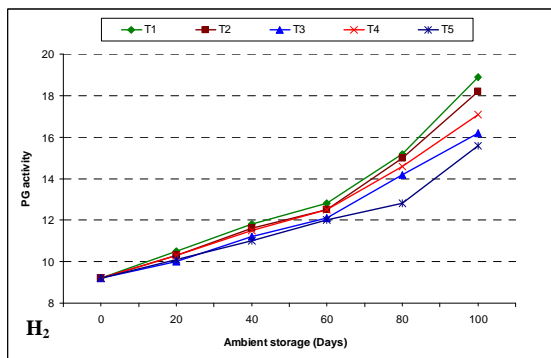
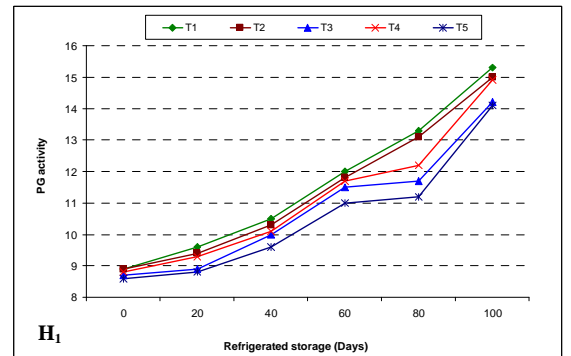
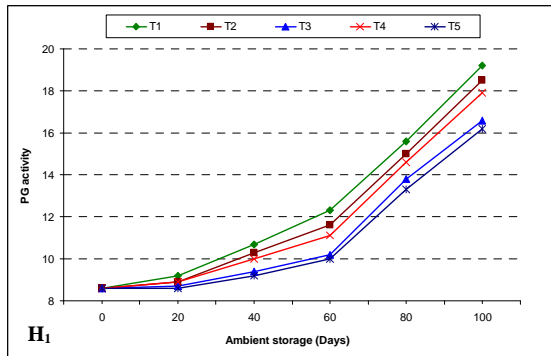


Fig. 8 : Effect of harvest dates, post harvest treatments and storage conditions on polygalactouronase activity (% loss in viscosity) activity of apple

4.3 Sensory evaluation

4.3.1 Colour score

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on colour score of “Red Delicious” apple under ambient conditions is presented in Table 21. A mean maximum colour score of 4.99 was observed in H₂ and minimum of 4.88 in H₁ at 0 day of storage.

Among treatments, highest colour score of 4.83, 4.94 and 4.94 was observed for T₅, while T₁ recorded the lowest mean colour score of 4.66, 4.67 and 4.68 in three harvest dates H₁, H₂ and H₃, respectively.

There was significant decrease in colour score during storage of 100 days under ambient conditions. Mean value of colour score decreased from 4.95 at 0 day to 4.67 after 100 days of storage.

Table 21 shows data pertaining to the effect of harvest dates, postharvest treatments and storage periods on colour score of “Red Delicious” apple under refrigerated conditions. A mean maximum colour score of 4.99 was observed in H₂ and minimum of 4.88 in H₁ at 0 day of storage.

Postharvest treatments showed a significant effect on colour score. Highest colour score of 4.86, 4.95 and 4.96 was observed for T₅ while as T₁ recorded the lowest mean colour score of 4.83, 4.94 and 4.94 in three harvest dates H₁, H₂ and H₃, respectively.

Mean value of colour score decreased significantly from 4.95 at 0 day to 4.79 after 100 days of storage under refrigerated conditions.

4.3.2 Texture score

Table 22 depicts data pertaining to the effect of harvest dates, postharvest treatments and storage periods on texture score of “Red Delicious” apple under ambient conditions. A mean maximum texture score of 5.00 was observed in H₁ and minimum of 4.79 in H₃ at 0 days of storage.

Table-21 : Effect of harvest dates, post harvest treatments and storage conditions on sensory colour of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	4.88	4.88	4.88	4.78	4.68	4.48	4.66	4.88	4.88	4.88	4.88	4.78	4.68	4.83
	T ₂	4.88	4.88	4.88	4.78	4.68	4.48	4.68	4.88	4.88	4.88	4.88	4.78	4.68	4.83
	T ₃	4.88	4.88	4.88	4.88	4.78	4.58	4.71	4.88	4.88	4.88	4.88	4.88	4.78	4.83
	T ₄	4.88	4.88	4.88	4.78	4.68	4.48	4.76	4.88	4.88	4.88	4.88	4.78	4.68	4.86
	T ₅	4.88	4.88	4.88	4.88	4.78	4.68	4.83	4.88	4.88	4.88	4.88	4.88	4.78	4.86
	Sub Mean	4.88	4.88	4.88	4.82	4.72	4.54	4.79	4.88	4.88	4.88	4.88	4.82	4.72	4.84
H ₂	T ₁	4.99	4.99	4.99	4.89	4.79	4.69	4.67	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₂	4.99	4.99	4.99	4.89	4.79	4.69	4.69	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₃	4.99	4.99	4.99	4.99	4.89	4.79	4.74	4.99	4.99	4.99	4.99	4.89	4.89	4.95
	T ₄	4.99	4.99	4.99	4.89	4.79	4.69	4.89	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₅	4.99	4.99	4.99	4.99	4.89	4.79	4.94	4.99	4.99	4.99	4.99	4.89	4.89	4.95
	Sub Mean	4.99	4.99	4.99	4.93	4.83	4.73	4.91	4.99	4.99	4.99	4.99	4.89	4.83	4.94
H ₃	T ₁	4.99	4.99	4.99	4.89	4.79	4.69	4.68	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₂	4.99	4.99	4.99	4.89	4.79	4.69	4.70	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₃	4.99	4.99	4.99	4.99	4.89	4.79	4.89	4.99	4.99	4.99	4.99	4.89	4.89	4.96
	T ₄	4.99	4.99	4.99	4.89	4.79	4.69	4.92	4.99	4.99	4.99	4.99	4.89	4.79	4.94
	T ₅	4.99	4.99	4.99	4.99	4.89	4.79	4.94	4.99	4.99	4.99	4.99	4.89	4.89	4.96
	Sub Mean	4.99	4.99	4.99	4.93	4.83	4.73	4.91	4.99	4.99	4.99	4.99	4.89	4.83	4.95
Grand Mean	4.95	4.95	4.95	4.89	4.79	4.67	4.87	4.95	4.95	4.95	4.95	4.87	4.79	4.91	
CD (p≤0.05)							CD (p≤0.05)								
			Harvest (H) = 0.108				Harvest (H) = 0.077								
			Treatment (T) = 0.102				Treatment (T) = 0.092								
			H x T = 0.107				H x T = 0.095								
			Storage (S) = 0.087				Storage (S) = 0.081								
			H x S = NS				H x S = NS								
			H x S x T = NS				H x S x T = NS								

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Table-22 : Effect of harvest dates, post harvest treatments and storage conditions on sensory texture of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	5.00	4.67	4.47	4.07	3.67	3.27	4.19	5.00	4.87	4.67	4.57	4.27	3.97	4.56
	T ₂	5.00	4.77	4.57	4.17	3.77	3.37	4.28	5.00	4.87	4.67	4.57	4.27	3.97	4.56
	T ₃	5.00	4.87	4.67	4.37	3.97	3.77	4.44	5.00	4.97	4.77	4.67	4.57	4.27	4.71
	T ₄	5.00	4.77	4.57	4.17	3.77	3.37	4.28	5.00	4.87	4.67	4.47	4.37	4.07	4.58
	T ₅	5.00	4.87	4.67	4.47	4.07	3.97	4.51	5.00	4.97	4.77	4.67	4.57	4.47	4.74
	Sub Mean	5.00	4.79	4.59	4.25	3.85	3.55	4.34	5.00	4.91	4.71	4.59	4.41	4.15	4.63
H ₂	T ₁	4.90	4.58	4.38	3.98	3.58	3.18	4.10	4.90	4.68	4.58	4.48	4.18	4.08	4.48
	T ₂	4.90	4.68	4.48	4.08	3.58	3.18	4.15	4.90	4.68	4.58	4.48	4.18	4.08	4.48
	T ₃	4.90	4.78	4.68	4.28	3.78	3.48	4.32	4.90	4.88	4.68	4.58	4.48	4.38	4.65
	T ₄	4.90	4.68	4.48	4.08	3.58	3.28	4.27	4.90	4.68	4.58	4.58	4.38	4.28	4.57
	T ₅	4.90	4.88	4.78	4.48	4.18	3.38	4.43	4.90	4.88	4.78	4.68	4.58	4.58	4.73
	Sub Mean	4.90	4.72	4.56	4.18	3.74	3.30	4.25	4.90	4.76	4.64	4.56	4.36	4.28	4.58
H ₃	T ₁	4.79	4.49	4.29	4.09	3.69	3.29	4.11	4.79	4.69	4.59	4.49	4.29	3.99	4.47
	T ₂	4.79	4.49	4.29	4.09	3.69	3.29	4.11	4.79	4.69	4.59	4.49	4.29	3.99	4.47
	T ₃	4.79	4.59	4.49	4.29	3.89	3.49	4.26	4.79	4.79	4.69	4.59	4.49	4.29	4.61
	T ₄	4.79	4.59	4.39	4.19	3.79	3.39	4.19	4.79	4.69	4.69	4.59	4.39	4.09	4.54
	T ₅	4.79	4.59	4.49	4.49	4.19	3.99	4.43	4.79	4.79	4.69	4.69	4.59	4.59	4.69
	Sub Mean	4.79	4.55	4.39	4.23	3.85	3.49	4.22	4.79	4.73	4.65	4.57	4.41	4.19	4.56
Grand Mean	4.90	4.69	4.51	4.22	3.81	3.43	4.27	4.90	4.80	4.67	4.57	4.39	4.21	4.59	
		CD (p=0.05)							CD (p=0.05)						
		Harvest (H) = NS							Harvest (H) = NS						
		Treatment (T) = 0.014							Treatment (T) = 0.010						
		H x T = 0.011							H x T = 0.014						
		Storage (S) = 0.321							Storage (S) = 0.317						
		H x S = 0.247							H x S = 0.253						
		H x S x T = 0.334							H x S x T = 0.348						

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

Postharvest treatments showed a significant effect on texture score. Highest texture score of 4.51, 4.43 and 4.43 was observed for T₅ while as T₁ recorded the lowest mean texture score of 4.19, 4.10 and 4.4.11 in three harvest dates H₁, H₂ and H₃, respectively.

Mean value of texture score decreased from 4.90 at 0 day to 3.43 after 100 days of storage. There was significant decrease in texture score during storage of 100 days under ambient conditions.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on texture score of “Red Delicious” apple under refrigerated conditions is presented in Table 22. A mean maximum texture score of 5.00 was observed in H₁ and minimum of 4.79 in H₃ at 0 day of storage.

Among treatments, highest texture score of 4.74, 4.73 and 4.69 was observed for T₅ while as T₁ recorded the lowest mean texture score of 4.56, 4.48 and 4.47 in three harvest dates H₁, H₂ and H₃, respectively and postharvest treatments showed a significant effect on texture score.

There was significant decrease in texture score during storage of 100 days under ambient conditions. Mean value of texture score decreased from 4.90 at 0 day to 4.21 after 100 days of storage.

4.3.3 Flavour score

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on flavour score of “Red Delicious” apple under ambient conditions is presented in Table 23. A mean maximum flavour score of 4.90 was observed in H₂ and minimum of 4.57 in H₁ at 0 day of storage.

Postharvest treatments showed a significant effect on flavour score. Highest flavour score of 4.49, 4.57 and 4.44 was observed in T₅, while T₁ recorded the lowest mean flavour score of 4.27, 4.33 and 4.22 in three harvest dates H₁, H₂ and H₃, respectively.

Table-23 : Effect of harvest dates, post harvest treatments and storage conditions on sensory flavour of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	4.57	4.67	4.47	4.17	3.97	3.77	4.27	4.57	4.67	4.57	4.27	4.17	4.07	4.39
	T ₂	4.57	4.67	4.47	4.27	4.07	3.87	4.32	4.57	4.67	4.57	4.37	4.27	4.07	4.42
	T ₃	4.57	4.67	4.57	4.47	4.37	4.17	4.47	4.57	4.67	4.57	4.47	4.37	4.37	4.50
	T ₄	4.57	4.67	4.47	4.37	4.07	3.97	4.35	4.57	4.67	4.57	4.37	4.27	4.17	4.44
	T ₅	4.57	4.67	4.57	4.47	4.37	4.27	4.49	4.57	4.67	4.57	4.47	4.37	4.37	4.50
	Sub Mean	4.57	4.67	4.51	4.35	4.17	4.01	4.38	4.57	4.67	4.57	4.39	4.29	4.21	4.45
H ₂	T ₁	4.90	4.60	4.40	4.20	4.00	3.90	4.33	4.90	4.70	4.60	4.40	4.30	4.20	4.52
	T ₂	4.90	4.60	4.40	4.20	4.00	3.90	4.33	4.90	4.70	4.60	4.40	4.30	4.20	4.52
	T ₃	4.90	4.70	4.60	4.30	4.10	4.10	4.45	4.90	4.70	4.60	4.50	4.40	4.30	4.57
	T ₄	4.90	4.50	4.30	4.10	3.90	3.80	4.25	4.90	4.70	4.50	4.30	4.20	4.10	4.45
	T ₅	4.90	4.80	4.60	4.40	4.30	4.40	4.57	4.90	4.70	4.60	4.50	4.50	4.40	4.60
	Sub Mean	4.90	4.64	4.46	4.24	4.06	4.02	4.39	4.90	4.70	4.58	4.42	4.34	4.24	4.53
H ₃	T ₁	4.77	4.37	4.27	4.07	3.97	3.87	4.22	4.77	4.57	4.47	4.37	4.27	4.17	4.44
	T ₂	4.77	4.37	4.27	4.07	3.97	3.87	4.22	4.77	4.57	4.47	4.37	4.27	4.17	4.44
	T ₃	4.77	4.57	4.37	4.17	4.07	3.97	4.32	4.77	4.67	4.57	4.47	4.37	4.27	4.52
	T ₄	4.77	4.27	4.17	3.97	3.87	3.67	4.12	4.77	4.47	4.27	4.17	4.07	3.87	4.27
	T ₅	4.77	4.57	4.47	4.37	4.27	4.17	4.44	4.77	4.77	4.67	4.57	4.47	4.37	4.60
	Sub Mean	4.77	4.43	4.31	4.13	4.03	3.91	4.26	4.77	4.61	4.49	4.39	4.29	4.17	4.45
Grand Mean	4.75	4.58	4.43	4.24	4.09	3.98	4.34	4.75	4.66	4.55	4.40	4.31	4.21	4.48	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H) =			0.124				Harvest (H) =			0.113			
		Treatment (T) =			0.107				Treatment (T) =			0.109			
		H x T =			NS				H x T =			NS			
		Storage (S) =			0.112				Storage (S) =			0.105			
		H x S =			NS				H x S =			NS			
		H x S x T =			NS				H x S x T =			NS			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

There was significant decrease in flavour score during storage of 100 days under ambient conditions. Mean value of flavour decreased from 4.75 at 0 day to 3.98 after 100 days of storage.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on flavour score of “Red Delicious” apple under refrigerated conditions is presented in Table 23. A mean maximum flavour score of 4.90 was observed in H₂ and minimum of 4.57 in H₁ at 0 day of storage.

Postharvest treatments showed a significant effect on flavour score. Highest flavour score of 4.50, 4.60 and 4.60 was observed in T₅ while T₁ recorded the lowest mean flavour score of 4.39, 4.52 and 4.44 in three harvest dates H₁, H₂ and H₃, respectively.

Mean value of flavour score decreased from 4.75 at 0 day to 4.21 after 100 days of storage under refrigerated conditions and the decrease was statistically significant.

4.3.4 Overall acceptability score

Studies were carried out to analyze effect of harvest dates, postharvest treatments and storage periods on overall acceptability of “Red Delicious” apple under ambient conditions (Table 24). A mean maximum overall acceptability of 5.00 was observed in H₂ and minimum of 4.90 in H₃ at 0 day of storage.

Postharvest treatments showed a significant effect on overall acceptability score. Highest Overall acceptability score of 4.45, 4.41 and 4.30 was observed in T₅ while T₁ recorded the lowest mean overall acceptability score of 3.78, 3.96 and 3.82 in three harvest dates H₁, H₂ and H₃, respectively.

Mean value of overall acceptability score decreased significantly from 4.93 at 0 days to 3.23 after 100 days of storage under ambient conditions.

Data pertaining to the effect of harvest dates, postharvest treatments and storage periods on overall acceptability score of “Red Delicious” apple under

Table-24 : Effect of harvest dates, post harvest treatments and storage conditions on overall acceptability of apple

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₁	4.90	4.46	3.96	3.46	3.16	2.76	3.78	4.90	4.76	4.46	4.16	3.96	3.66	4.32
	T ₂	4.90	4.56	4.16	3.76	3.36	2.96	3.95	4.90	4.76	4.46	4.36	4.16	3.86	4.42
	T ₃	4.90	4.66	4.66	4.26	3.96	3.56	4.33	4.90	4.86	4.66	4.56	4.36	4.16	4.58
	T ₄	4.90	4.56	4.46	4.06	3.76	3.26	4.17	4.90	4.86	4.46	4.36	4.16	3.96	4.45
	T ₅	4.90	4.76	4.66	4.46	4.16	3.76	4.45	4.90	4.86	4.76	4.66	4.46	4.26	4.65
	Sub Mean	4.90	4.60	4.38	4.00	3.68	3.26	4.14	4.90	4.82	4.56	4.42	4.22	3.98	4.48
H ₂	T ₁	5.00	4.67	4.17	3.67	3.27	2.97	3.96	5.00	4.77	4.57	4.37	4.17	3.87	4.46
	T ₂	5.00	4.77	4.27	3.77	3.37	3.17	4.06	5.00	4.87	4.67	4.47	4.37	4.07	4.58
	T ₃	5.00	4.87	4.47	3.97	3.77	3.57	4.28	5.00	4.97	4.87	4.67	4.57	4.37	4.74
	T ₄	5.00	4.87	4.37	3.87	3.57	3.37	4.18	5.00	4.87	4.77	4.47	4.27	4.07	4.58
	T ₅	5.00	4.87	4.57	4.17	3.97	3.87	4.41	5.00	4.97	4.87	4.67	4.57	4.47	4.76
	Sub Mean	5.00	4.81	4.37	3.89	3.59	3.39	4.18	5.00	4.89	4.75	4.53	4.39	4.17	4.62
H ₃	T ₁	4.90	4.46	4.06	3.86	3.16	2.46	3.82	4.90	4.66	4.36	4.26	4.06	3.56	4.30
	T ₂	4.90	4.56	4.26	3.96	3.56	2.96	4.03	4.90	4.76	4.46	4.36	4.06	3.76	4.38
	T ₃	4.90	4.76	4.46	4.16	3.76	3.26	4.22	4.90	4.76	4.66	4.56	4.36	4.16	4.57
	T ₄	4.90	4.56	4.36	3.96	3.46	3.06	4.05	4.90	4.76	4.56	4.46	4.16	3.96	4.47
	T ₅	4.90	4.76	4.46	4.26	3.96	3.46	4.30	4.90	4.86	4.66	4.56	4.46	4.26	4.62
	Sub Mean	4.90	4.62	4.32	4.04	3.58	3.04	4.08	4.90	4.76	4.54	4.44	4.22	3.94	4.47
Grand Mean	4.93	4.68	4.36	3.98	3.62	3.23	4.13	4.93	4.82	4.62	4.46	4.28	4.03	4.52	
		CD (p≤0.05)							CD (p≤0.05)						
		Harvest (H)			= 0.01				Harvest (H)			= 0.02			
		Treatment (T)			= 0.03				Treatment (T)			= 0.03			
		H x T			= 0.05				H x T			= 0.06			
		Storage (S)			= 0.09				Storage (S)			= 0.10			
		H x S			= 0.12				H x S			= 0.13			
		H x S x T			= 0.13				H x S x T			= 0.15			

T₁ = Shade cooling (Control); T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

refrigerated conditions is presented in Table 24. A mean maximum overall acceptability score of 5.00 was observed in H₂ and minimum of 4.90 in H₃ at 0 days of storage.

Highest overall acceptability score of 4.65, 4.76 and 4.62 was observed in T₅, while T₁ recorded the lowest mean overall acceptability score of 4.32, 4.46 and 4.30 in three harvest dates H₁, H₂ and H₃, respectively. Postharvest treatments showed a significant effect on overall acceptability score.

There was significant decrease in overall acceptability score during storage of 100 days under ambient conditions. Mean value of overall acceptability score decreased from 4.93 at 0 days to 4.03 after 100 days of storage.

4.4 Economic feasibility estimates

The effect of harvest dates, post harvest treatments and storage period on relative economics of “Red Delicious” apple stored under ambient condition is presented in Table 25. The analysis was carried out at three different harvest dates for different treatments in each harvest date. The results reveal that the effect of post harvest treatments was significant. The higher return of 1.96, 2.60 and 2.53 for each rupee invested was recorded in all harvest dates H₁, H₂ and H₃, respectively.

The mean value of return increased significantly from 0.00 at 0 day to 2.87 after 100 days of storage under ambient conditions. Table 25 shows the effect of harvest dates, postharvest treatments and storage on “Red Delicious” apple under refrigerated storage.

Treatments showed significant effect on return to the treatment cost. The highest return of 3.76, 4.00 and 3.86 were recorded for T₅ (Hydrocooling + Calcium Chloride + Wax), while lowest return of 3.30, 3.50 and 3.30 were recorded for T₂ in all harvest dates H₁, H₂ and H₃, respectively.

Mean value of return increased from 0.00 at 0 day to 4.63 after 100 days of storage under refrigerated environment.

Table-25 : Economic feasibility estimation

Harvest dates	Storage Treatment	Ambient storage (Days)							Refrigerated storage (Days)						
		0	20	40	60	80	100	Mean	0	20	40	60	80	100	Mean
H ₁	T ₂	0.00	1.07	1.33	1.33	2.00	2.67	1.40	0.00	1.71	2.91	3.73	3.79	4.35	3.30
	T ₃	0.00	1.43	1.90	1.90	2.86	2.86	1.83	0.00	2.68	2.95	3.83	4.55	4.96	3.79
	T ₄	0.00	1.06	1.28	1.70	2.13	2.77	1.49	0.00	1.19	2.87	3.78	4.09	4.08	3.20
	T ₅	0.00	1.51	1.96	2.08	3.02	3.21	1.96	0.00	2.74	3.01	3.89	4.59	4.58	3.76
	Sub Mean	0.00	1.27	1.62	1.75	2.50	2.87	1.67	0.00	2.08	2.94	3.81	4.26	4.49	3.51
H ₂	T ₂	0.00	1.33	1.33	1.73	2.00	2.67	1.81	0.00	1.83	3.09	3.87	4.21	4.52	3.50
	T ₃	0.00	1.90	2.38	2.86	2.86	2.95	2.59	0.00	2.93	3.28	3.95	4.75	5.04	3.99
	T ₄	0.00	1.49	1.49	2.13	2.34	2.77	2.04	0.00	1.94	3.10	3.93	4.25	4.76	3.60
	T ₅	0.00	2.08	2.26	2.26	3.02	3.40	2.60	0.00	3.01	3.44	4.25	4.81	4.90	4.00
	Sub Mean	0.00	1.70	1.87	2.25	2.55	2.95	2.26	0.00	2.43	3.23	4.00	4.51	4.86	3.80
H ₃	T ₂	0.00	1.33	1.47	1.60	2.00	2.40	1.76	0.00	1.71	2.91	3.60	4.11	4.17	3.30
	T ₃	0.00	1.90	2.10	2.38	2.86	2.95	2.44	0.00	2.20	3.11	3.83	4.46	4.88	3.69
	T ₄	0.00	1.49	1.53	2.09	2.30	2.55	1.99	0.00	1.79	2.99	3.64	4.17	4.29	3.38
	T ₅	0.00	2.04	2.19	2.26	2.94	3.21	2.53	0.00	2.88	3.33	3.89	4.36	4.84	3.86
	Sub Mean	0.00	1.69	1.82	2.08	2.52	2.78	2.18	0.00	2.14	3.09	3.74	4.27	4.54	3.56
Grand Mean		0.00	1.55	1.77	2.03	2.52	2.87	2.04	0.00	2.22	3.09	3.85	4.35	4.63	3.62

T₂ = Hydro cooling; T₃ = Hydro cooling + CaCl₂; T₄ = Hydro cooling + wax; T₅ = Hydro cooling + CaCl₂ + wax

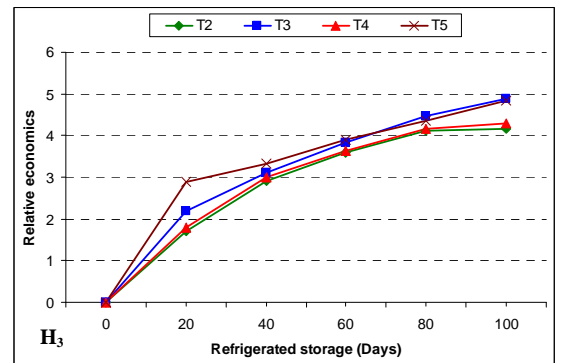
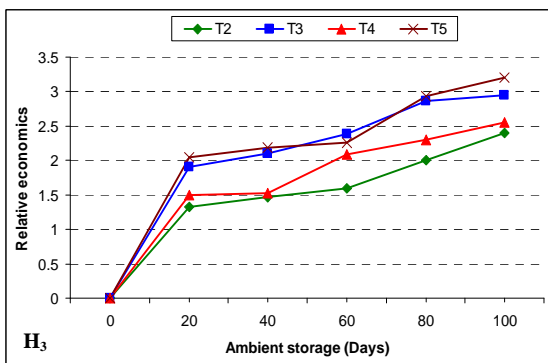
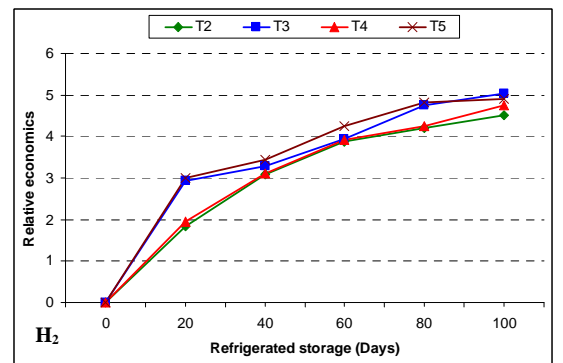
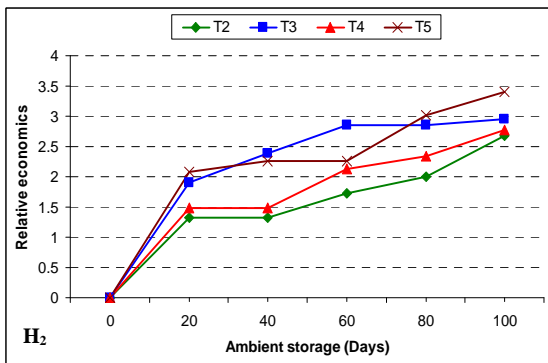
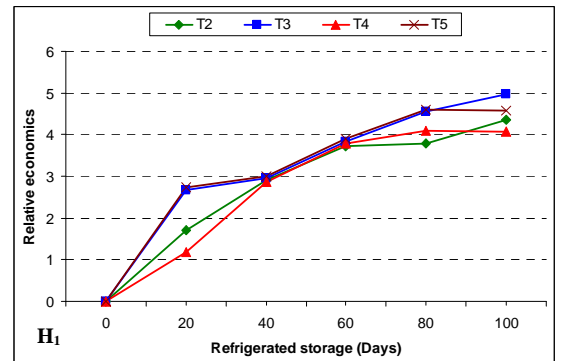
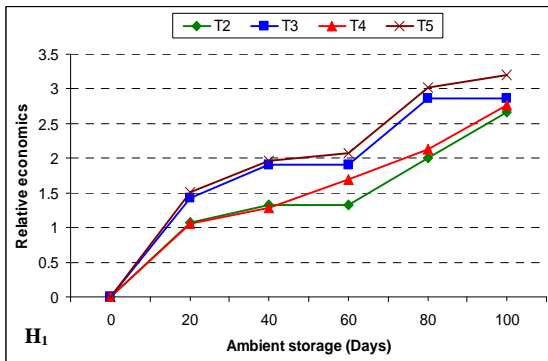


Fig. 9 : Economic feasibility estimation

Chapter – 5

DISCUSSION

5.1 Physical Parameters

5.1.1 Fruit length (mm)

A significant variation was observed in Fruit length at different harvest dates. The mid harvested (H_2) fruits showed maximum fruit length (74.21 mm) while as early harvested (H_1) apples showed minimum fruit length (72.32 mm). After the 100 days of storage mid harvested apples (H_2) proved to be the best to retain maximum fruit length. The possible reason behind the retention might be the less water loss and shrinkage than early and late harvested apples. These results are in accordance with Zerbini *et al.* (1999), Juan *et al.* (1999).

Among the treatments T_5 (Hydrocooling + $CaCl_2$ + wax) remained the best treatment to retain maximum fruit length while T_1 (shade cooling) showed the minimum fruit length. The reason behind might be the effect of $CaCl_2$ and wax coating on the moisture loss and retardation of respiration (Bai *et al.*, 2003). It is clear from the (Table-1) that there is a continuous decrease in fruit length throughout the storage period. These results are in conformity with those reported by Khorshidi *et al.* (2010). Decrease in fruit length was more pronounced in ambient storage than in refrigerated storage.

5.1.2 Fruit diameter (mm)

Among different dates studied, early (H_1) and late harvested (H_3) fruit, showed minimum fruit diameter of 66.57 and 67.24 mm, respectively while fruits harvested at mid stage (H_2) showed the maximum fruit diameter (67.35 mm).

After 100 days of storage mid harvest (H_2) fruit recorded the maximum fruit diameter. The possible reason might be the full cuticle development which prevents the shrinkage while as the reason for the minimum fruit diameter in H_1

and H₃ might be less cuticle development and more respiration, respectively. These results are in accordance with Zerbini (1999) and Juan *et al.* (1999).

Among the treatments T₅ (Hydrocooling + CaCl₂ + wax) recorded the maximum fruit diameter. Protective effect of CaCl₂ and wax on moisture loss and shrinkage can be the possible reason. These findings are in agreement with Bai *et al.* (2003). As it is clear from the Table 2 that there was continuous decrease in fruit diameter throughout the storage in all treatments and harvest dates. The reason might be moisture loss and shrinkage (Khorshidi *et al.*, 2010). Decrease in fruit diameter was more pronounced in ambient storage than in refrigerated storage.

5.1.3 L/D ratio

During the study period L/D ratio changed according to the harvest dates and varied significantly at different dates. Late harvested (H₃) apples recorded the maximum L/D ratio (1.08) while fruits harvested at early maturity (H₁) recorded the minimum L/D ratio. After 100 days of storage, fruits harvested at late maturity stage (H₃) showed the maximum L/D ratio while fruits harvested at early maturity (H₁) showed minimum L/D ratio. These results resemble with the statement of Kvikliene *et al.* (2008).

All the treatments showed non-significant effect on L/D ratio. The reason for non-significant effect on L/D most probably is that we calculate L/D ratio from length and breadth both of which showed similar decreasing trend. As it is clear from the Table 3 that there is no effect of storage on L/D ratio. Ambient storage showed more prominent changes than refrigerated storage.

5.1.4 Fruit weight (g)

Late harvested apples showed the maximum fruit weight (166.40 g) while as early harvested fruits showed minimum fruit weight (164.40 g) when effect of harvesting dates was studied. After the storage period of 100 days fruit harvested

at mid maturity (H₂) proved best to retain the maximum fruit weight. These results resemble with the work of Maguire *et al.* (2000).

Among the treatments T₅ (Hydrocooling + CaCl₂ + wax) proved best to retain maximum fruit weight whereas T₁ (shade cooling) recorded the minimum fruit weight. The reason behind the retention of maximum fruit weight by T₅ might be the protective effect of calcium chloride and wax coating on moisture loss hence more fruit weight. These results are in agreement with the statement of Bai *et al.* (2003).

There was continuous decrease in fruit weight during the storage period in all treatments as well as in harvest dates (Table-4) both under ambient as well as refrigerated storage conditions. Refrigerated storage recorded less changes than ambient storage. The reason might be the continuous respiration and water loss. These results are based on the statement of Khorshidi *et al.* (2010). Decrease in fruit weight was more pronounced in ambient storage than in refrigerated storage.

5.1.5 Fruit firmness (lb/inch²)

Fruit flesh firmness is an important criterion for edible quality and market value of apples and loss of fruit flesh firmness is a serious problem resulting in quality losses (Kov *et al.*, 2005). During storage study period, fruit firmness changed according to harvest dates and differed significantly at different dates. Later harvested (H₃) fruits had lower firmness (18.60 lb/inch²) than H₂ (19.40 lb/inch²) and H₁ (19.70 lb/inch²). After 100 days of storage apples harvested at H₂ were of best quality. Roth *et al.* (2005) reported that later harvested fruits had shown lower firmness both at harvesting time and at the end of storage period too.

The higher values of firmness in early harvested fruits (H₁) may be due to the higher calcium pectate content in early harvested fruits. Moreover, in early harvested fruits the enzyme activity is low especially polygalacturonase which results in less degradation of cell wall and hence more firmness.

Among different treatments, T₁ (Control) recorded minimum firmness at all harvesting stages while maximum firmness was recorded in case of T₅ (Hydrocooling + CaCl₂ + Wax). This might be due to the fact that hydrocooling, CaCl₂ and wax had negative effect on moisture loss and enzyme activity which helps in maintaining firmness. Similar results regarding effect of CaCl₂ and Wax were reported by Wijewardane *et al.* (2009). Furthermore, CaCl₂ forms a thin layer on surface of fruits which delays degradation process and also reduces evaporation from fruits (Tabatabaie *et al.*, 1998; Hayat *et al.*, 2003). Wax coating results in decrease in moisture loss (Bai *et al.*, 2002). As it is evident from Table 5 that with prolonged storage there is decrease in fruit firmness. This decrease in firmness might be due to hydrolysis of pectin during storage which resulted in decreased firmness (Brummell *et al.*, 2001; Mir *et al.*, 2004). More prominent changes in fruit firmness were observed under ambient storage than refrigerated storage.

5.1.6 Colour (L*, a*, b* values)

During the experiment period fruit colour L*, a*, b* values changed as per the harvest dates and differed significantly at each harvest date. Early harvested apples H₁ recorded the maximum L* and b* values (40.60 and 16.90) whereas recorded the minimum values for a* (30.50).

After the storage period of 100 days fruits harvested at late maturity H₂ received the minimum values for L* and b* whereas maximum values for a* was recorded by fruits harvested at late stage of maturity (H₃). The reason behind the higher a* values in harvest date third (H₃) might be the full pigment development upto late stages of maturity. These results are in agreement with Kvikliene *et al.* (2008).

Among the treatments treatment T₅ (Hydrocooling + CaCl₂ + wax) recorded the minimum values of L* and b* whereas it received maximum values for a*. The reason behind the higher a* values recorded by T₅ might be protective

effect of CaCl_2 and wax on degradation of pigments. These results are in conformation with Bai *et al.* (2003).

As it is evident from the Table-6, 6.1 and 6.2 there was continuous increase in L^* and b^* values and decrease in a^* values during the storage period irrespective of treatment and harvest dates. The reason behind this increase in L^* and b^* values and decrease in a^* values might be the pigment degradation during the storage. These results are in accordance with Henriquez *et al.* (2010). Colour changes were more pronounced in ambient storage than in refrigerated storage.

5.1.7 Rot incidence (%)

The soft rot of apple fruit is due to the development of brown and watery lesions on the skin of the apple that generally extend into the flesh (Watkins and Rosenberger, 2002). During present study period rot incidence did not appear for all the harvest dates changed according to harvest dates and differed significantly at different dates. The maximum rot incidence was observed in H_3 and minimum in H_2 . Among the treatments T_5 (hydro-cooling+ CaCl_2 +wax) was found best (Table 7). The lower rot incidence in T_5 might be because of the water used in hydro-cooling which decreases the initial microbial load, moreover wax creates a barrier to the invasion of pathogen. The mean soft rot incidence significantly increased during storage and the increase was more in fruits harvested at later stage of maturity than fruits harvested at mid or early maturity stages (Kader, 1985). It is a common observation that the fruits are more susceptible to different pathogens as they advance in ripening (Robertson *et al.*, 1990) due to either senescence (Murray *et al.*, 1998) or more susceptibility to mechanical injury (Kader, 2002). The decreased soft rot incidence with increased calcium concentration may be due to the calcium-induced delay in natural ripening and senescence (Agar *et al.*, 1999), which makes the fruit susceptible to pathogens. In general fruits stored under refrigerated conditions showed less rot incidence than ambient storage.

5.1.8 Physiological loss in weight (%)

Moisture content of fruits is a major quality criteria (Gorini *et al.*, 1979; Hatfield and Knee, 1988) and its loss from the fruits is serious consideration. Moisture loss decreases the visual quality and contributes to the loss of turgor pressure and subsequent softening (Vander-Beng, 1981). After 100 days of storage apples harvested at H₁ (8.74%) showed maximum weight loss and minimum was observed in H₁ (8.43%). Among treatments T₅ was found best and showed minimum weight loss (Table 8). Since, the weight loss in fruit depends on moisture loss (Bidabe *et al.*, 1970; Ghafir *et al.*, 2009), which is regulated by epicuticular waxes which increase with maturation (Lau, 1992). The high weight loss in fruit harvested at early stage of maturation may be due to poorly developed waxy surface and cuticle (Ihabi *et al.*, 1998; Sass and Lakner, 1998). The weight loss in fruits increased linearly with increase in storage duration due to water loss and respiration (Blampired, 1981; El-Shennawi, 1989; Gavlheiro *et al.*, 2003; Erturk, 2003; Ghafir *et al.*, 2009). The decrease in weight loss with increase in CaCl₂ + wax is in accordance with Ashore, (2000) and Hayat *et al.* (2003). Ambient storage showed higher PLPW than refrigerated storage.

5.2 Chemical parameters

5.2.1 Moisture content (%)

During storage study period results revealed that moisture changed according to harvest dates and differed significantly at different dates. Later harvested (H₃) fruits had lower moisture content (80.89%) than H₂ (81.84%) and H₁ (82.60%). After 100 days of storage apples harvested at H₂ were of best quality.

Later harvested fruits had shown lower moisture content both at harvesting time and at the end of storage period too (Yong *et al.*, 1998).

The higher values of moisture in early harvested fruits (H₁) may be due to smaller fruit sizes effects as there is more moisture loss during early harvested

fruits because of immature cuticle formation. Moreover, in early harvested fruits the enzyme activity is predominantly more especially PME which results in more degradation and hence increase in TSS.

5.2.2 Total Soluble Solids (^oBrix)

Total soluble solids of apple and other fruits is a major quality parameter (Weibel *et al.*, 2004; Peck *et al.*, 2006). During storage study period TSS changed according to harvest dates and differed significantly at different dates. Later harvested (H₃) fruits had higher TSS content (14.84 ^oBrix) than H₂ (14.38 ^oBrix) and H₁ (14.17 ^oBrix). After 100 days of storage apples harvested at H₂ were of best quality. Later harvested fruits had shown higher TSS both at harvesting time and at the end of storage period too (Yong *et al.*, 1998). The higher values of TSS in early harvested fruits (H₁) may be due to concentration effects as there is more moisture loss during early harvested fruits because of immature cuticle formation. Moreover, in early harvested fruits the enzyme activity is predominantly more especially PME which results in more degradation and hence increase in TSS.

Among different treatments, T₁ (Control) recorded maximum TSS at all harvesting stages while as minimum TSS was recorded incase of T₅ (Hydrocooling + CaCl₂ + Wax). This might be due to the fact that both CaCl₂ and Wax had negative effect on moisture loss which results in lower TSS due to dilutions of solids. Similar results regarding effect of CaCl₂ and Wax were reported by Badshah *et al.* (1994) and Hussain (2001) Furthermore, CaCl₂ (3%) forms a thin layer on surface of fruits which delays degradation process and also reduces evaporation from fruits (Hayat *et al.*, 2003). Wax coating results in decrease in moisture loss. As it is evident from Table 10 that with prolonged storage there is increase in TSS. This increase in TSS might be due to hydrolysis of polysaccharide during storage which resulted in increase in TSS (Hayat *et al.*, 2003; Mir *et al.*, 2004). Refrigerated storage resulted in lesser increase in TSS than ambient.

5.2.3 Acidity (%)

Apple cultivars have been shown to have significant differences in acidity (Ali *et al.*, 2004). During storage study period total acidity changed according to harvest dates and differed significantly at different dates. Early harvested (H₁) fruits had higher acidity (0.363%) than H₂ (0.351%) and H₃ (0.330%). After 100 days of storage apples harvested at H₂ were of best quality. Early harvested fruits had shown higher acidity at harvesting time but lower at the end of storage period (Yong *et al.*, 1998).

The lower values of acidity in late harvested fruits (H₃) may be due to the breakdown of organic acids as a main respiratory substrate. Among different treatments, T₁ (Control) recorded minimum acidity at all harvesting stages. While maximum acidity was recorded in case of T₅ (hydrocooling+ CaCl₂ + wax). This might be because of the fact that hydrocooling, CaCl₂ and wax reduces the respiration rate which results in maintained acidity over a long period. Similar results regarding effect of CaCl₂ and wax were reported by Hussain (2001). Furthermore, as per the data given in Table 3 (CaCl₂) delays degradation process and wax coating results in decrease in respiration rate. As it is evident from Table 11 that with prolonged storage there is decrease in acidity. This decrease in acidity might be due to oxidation of organic acids during storage which resulted in decrease in acidity (Drake and Spayed, 1983). Decrease in acidity was more pronounced in ambient storage than in refrigerated storage.

5.2.4 Total sugars (%)

The sugars content, sucrose, glucose, fructose, and sorbitol, in fruit flesh contribute to the fruit sweetness, and is one of the major characteristics of fruit quality and market value. The apple fruit accumulate starch at the early stages of maturation that is later on hydrolyzed to sugars at edible maturity (Magein and Leurquin, 2000). The starch to sugars conversion continues during storage (Beaudry *et al.*, 1989), resulting in increased total sugars with storage duration

(Bidabe *et al.*, 1970; Crouch, 2003). Results obtained during storage study period showed that fruit total sugars changed according to harvest dates and differed significantly at different dates. Later harvested (H_3) fruits showed higher sugar content (18.60%) than H_2 (19.40%) and H_1 (19.70%). After 100 days of storage apples harvested at H_2 were of best quality.

The lower values of total sugars in early harvested fruits (H_1) may be due to the higher starch content in early harvested fruits. Moreover, in early harvested fruits the starch degrading enzyme activity is low especially amylases which results in degradation of starch into simple sugars.

Among different treatments, T_1 (Control) recorded maximum total sugars at all harvesting stages. Minimum total sugars was recorded in case of T_5 (Hydrocooling + $CaCl_2$ + Wax). This might be due to the fact that hydrocooling, $CaCl_2$ and wax reduces enzyme activity which helps in maintaining the starch. Similar results regarding effect of $CaCl_2$ and wax were reported by Wijewardane *et al.* (2009). Furthermore, $CaCl_2$ forms a thin layer on surface of fruits which delays degradation process and also reduces evaporation from fruits (Hayat *et al.*, 2003). Wax coating results in decrease in moisture loss thus prevents concentration effect. As it is evident from Table 12 that with prolonged storage there is increase in total sugars. This increase in total sugars might be due to hydrolysis of starch and other higher polysaccharides during storage which resulted in higher total sugars (Brummell *et al.*, 2001; Mir *et al.*, 2004). When different storage conditions are evaluated, ambient storage caused a greater increase in total sugars than in refrigerated storage.

5.2.5 Juice content (%)

The juice content of apple fruit depends on water present in the fruit (Allan *et al.*, 2003). Juice content differed significantly at different dates during present study. Mid harvested (H_2) fruits had higher Juice content (49.50%) than H_3 (49.20%) and H_1 (49.20%). After 100 days of storage apples harvested at H_2 and

among treatments T₅ (hydro-cooling + CaCl₂ + wax) were of best quality (Table 13). The loss of juiciness is attributed to the loss of moisture during storage. Calcium chloride and wax coating materials prevented escape of water through fruit surface, thus explaining higher juice content in treated fruits compared to control. Gupta *et al.* (1987) also observed decrease in juice content of “Red Delicious” apple during storage. The juice content generally declined with increasing storage duration (Allan *et al.*, 2003). The significantly lower decrease in juice yield in samples treated with calcium chloride can be explained due to the inhibitory effect of combinatory treatments on physiological processes responsible for the loss of turgor pressure and membrane integrity (Hussain *et al.*, 2008). Decrease in juice content was more pronounced in ambient storage than in refrigerated storage.

5.2.6 Calcium content (mg/100g)

Calcium is an important quality parameter in fruits because it is constituent of cell wall. Calcium content changed according to harvest dates and differed significantly at different dates. Early harvested fruits (H₁) showed highest values (6.90 mg/100g) for calcium content while late harvested fruit (H₃) showed lowest values (6.70 mg/100g). After 100 days of storage fruits harvested at early maturity (H₁) showed the maximum calcium content at the time of harvesting and at the end of storage. The reason behind the more calcium in early harvested fruits might be reduced fruit size and more moisture loss during the storage. These results are in accordance with Gorinstein *et al.* (2001).

Among different treatments T₅ (hydrocooling + CaCl₂ + wax) recorded the maximum calcium content followed by T₃ (hydrocooling + calcium chloride) and the minimum calcium content was found in T₁ (shade cooling). The reason for higher calcium content in T₅ (hydrocooling + CaCl₂ + wax) might be because of the post harvest treatment with calcium chloride which increases the calcium content of apple fruit (Dewey and Lee, 1980). It is evident from the Table-14 there was continuous increase in calcium content among all the treatment and

harvest dates during storage. The reason behind may be loss in moisture which increases Ca concentration and not due to the synthesis or any other mechanism. Ambient storage caused more loss of moisture resulting in higher concentration of Ca than refrigerated storage.

5.2.7 Pectin content (%)

During the study, pectin content changed according to the harvest dates and varied significantly at different dates. Late harvested fruit H₃ showed minimum pectin content (1.38%) while early harvested apple H₁ showed maximum value of pectin (1.61%).

At the end of 100 days storage period early harvested apples retained the maximum pectin while late harvested apples showed minimum pectin content. The most probable reason for higher pectin content in early harvested apples might be due high calcium pectate in less mature fruits and low pectinolytic activity. These results are in accordance with Castro *et al.* (2007) and Kvikliene *et al.* (2008).

Among different treatments T₅ (hydrocooling + CaCl₂ + wax) proved to be the best treatment combination to retain maximum pectin content as compared to other treatments while T₁ (control) showed the minimum retention of pectin content. The main reason behind the retention of pectin by T₅ (hydrocooling + CaCl₂ + wax) might be due to slow down of the respiration rate as well as pectinolytic enzyme activity (which solublizes the pectin) because of hydrocooling, calcium chloride and wax treatment. These results are in conformation with Asthari (2004).

There was continuous decrease in pectin content throughout the storage period in all treatments (Table 15). This might be due to the enzyme activity particularly methyl pectin esterase and polygalactouranase (Wijewardane *et al.*, 2009; Nara *et al.*, 2001). Decrease in pectin content was more pronounced in ambient storage than in refrigerated storage.

5.2.8 Anthocyanin (mg/100g)

Anthocyanin changed according to harvest dates and varied significantly with each harvest date. Late harvested fruits H₃ showed highest anthocyanin (33.30 mg/100g) content while (H₁) early harvested showed minimum anthocyanin content (30.30 mg/100g).

After the 100 days of storage (H₃) late harvested apple retained the maximum anthocyanin content then H₁ and H₂. The reason behind the highest anthocyanin in late harvested apples might be due to full colour development by associated enzymes (PAL) and the lowest anthocyanin in H₁ early harvested apple might be due to more chlorophyll than anthocyanin.

Among the treatments T₅ (hydrocooling + CaCl₂ + wax) proved best to retain the maximum anthocyanin than other treatments. The reason behind this is the protective effect of precooling, CaCl₂ and wax an overall degradation of fruit Wijewardane and Guleria (2009).

As it is clear from the Table-16 that there was continuous decrease in anthocyanin content in all harvest dates as well as treatments. This may be due to the progressive senescence of fruit tissue which involves the degradation of pigments (Wijewardane and Guleria, 2011). Decrease in anthocyanin content was more pronounced in ambient storage than in refrigerated storage.

5.2.9 Ascorbic acid (mg/100g)

Ascorbic acid is usually considered as an index of nutrient quality in apple fruit. Ascorbic acid is a bioactive compound having antioxidant properties (Lata, 2007). During present study ascorbic acid changed according to harvest dates and differed significantly at different dates. Later harvested (H₃) fruits had higher ascorbic acid content (12.50 mg/100g) than H₂ (12.40 mg/100g) and H₁ (11.90 mg/100g). After 100 days of storage apples harvested at H₃ and among treatments T₅ (hydro-cooling + CaCl₂ + wax) were of best quality (Table 17).

Generally, the fruit harvested at early maturity had lower ascorbic acid indicating that the fruit may have still been synthesizing ascorbic acid when harvested at the early mature stages. Since the degradation of ascorbic acid is faster at higher than lower temperature (Pardio-Sedas *et al.*, 1994). The ascorbic acid loss during storage is known to be due to its antioxidant activity especially under postharvest storage conditions (Davey *et al.*, 2000). The ascorbic acid can be irreversible oxidized (Parviainen and Nyyssonen, 1992; Pardio-Sedas *et al.*, 1994), thus causing a decrease during storage (Jung and Watkins, 2008). The retention of relatively high ascorbic acid with the application of CaCl₂ and wax may due to the lower respiration rate and regulation of oxidative processes in the cytosol responsible for ascorbic acid degradation (Faust and Shear, 1972). Decrease in ascorbic acid was more pronounced in ambient storage than in refrigerated storage.

5.2.10 Polyphenol (mg/100g)

Harvest dates had a significant effect on total polyphenol. Early harvested fruits H₁ had shown maximum total polyphenol content (2.80 mg/100g) while mid harvested apples (H₂) showed minimum total polyphenol content (2.65 mg/100g). After the 100 days of storage period early harvested apples (H₁) showed the maximum polyphenol content than H₂ and H₃. The reason behind the higher level of polyphenol in early harvested apple (H₁) might be due to the reduced size, less break down and less ROS (Reactive oxygen species) production due to stress. Since polyphenols are natural scavengers of free radicals. These results are in accordance with Malina *et al.* (2005).

Among the treatments T₁ (shade cooling) recorded the minimum total phenol content while as T₅ (hydrocooling + CaCl₂ + wax) recorded the maximum concentration of total phenol. The main reason behind the higher polyphenol in T₅ (hydrocooling + CaCl₂ + wax) might be the protective effect of calcium chloride and wax coating an oxidative stress, hence less production of free radicals and less

break down of amino acids. These results are in accordance with Suzy *et al.* (1998).

It is evident from the (Table-18) that there was continuous decline in total polyphenol content throughout the storage period irrespective of harvest and treatments. This might be due to the more production of ROS during storage. Decrease in polyphenols was more pronounced in ambient storage than in refrigerated storage.

5.2.11 Pectin methyl esterase activity (MeOH equivalent) [$\mu\text{mole/litre/day}$]

Observations recorded depict that late harvested apples (H_3) showed highest pectin methyl esterase activity ($31.27 \mu\text{mole/litre/day}$) whereas early harvested apples (H_1) showed lowest pectin methyl esterase activity ($29.47 \mu\text{mole/litre/day}$).

After the 100 days storage the mid harvested apple H_2 recorded the minimum pectin methyl esterase activity while late harvested apples H_3 showed the maximum activity. The reason behind the lowest activity in H_2 might be the less activity of methyl pectin esterase enzyme in mature fruit than immature (Harriman *et al.*, 1991).

Among the treatments T_5 (hydrocooling + CaCl_2 + wax) recorded the minimum pectin methyl esterase activity while as T_1 (shade cooling) recorded the maximum activity. The reason behind the low activity in T_5 (hydrocooling + CaCl_2 + wax) might be the effect of treatments applied which are known to reduce enzyme activity (Wijewardane and Guleria, 2011).

There was a continuous increase in pectin methyl esterase activity throughout the storage period (Table-19). The reason behind this continuous increase might be de-esterification of polyuronides by removing methyl group from the C6 position of galacturonic acid residue of high molecular weight pectin. This demethylation of pectin to their free carboxyl groups changes the pH and change in cell wall, allows the aggregation of polyuronides into a calcium linked

gel structure, and makes the polyuronides susceptible to degradation by polygalactouronase (Pressey and Avants, 1982; Carpita and Gibeaut, 1993). Decrease in PME was more pronounced in ambient storage than in refrigerated storage.

5.2.12 Polygalacturonase activity (% loss in viscosity)

During the whole study interval viscosity changed according to harvest dates and differed significantly at different dates. The late harvested apples H₃ (10.20%) showed the highest loss of viscosity where as the fruits harvested at early (H₁) recorded the minimum (8.60%) loss of viscosity.

After the 100 days of storage mid harvested apples (H₂) showed the minimum loss of viscosity while as late harvested apples showed the maximum loss of viscosity. The most possible reason behind the higher viscosity loss in early (H₁) and late harvested apples (H₃) might be the higher pectin methyl esterase activity in early and late mature apples. These results are in accordance with Ray *et al.* (1988) and Harriman *et al.* (1991).

Among the treatments T₅ (hydrocooling + CaCl₂ + wax) proved best to retain the maximum quality whereas T₁ (control) retained the minimum quality. The reason behind the maximum quality retention by T₅ (hydrocooling + CaCl₂ + wax) might be due to the negative effect of hydrocooling and calcium chloride an enzyme activity. Moreover coating also reduces senescence and enzyme activity (Kleeberg, 1996).

As it is evident from the Table-20 there was a continuous increase in loss of viscosity throughout the investigations irrespective of harvest dates and treatments. The reason behind this loss of viscosity might be the increased activity of pectin methyl esterase and polygalacturonase during storage (Wijewardane and Guleria, 2009). Decrease in PG was more pronounced in ambient storage than in refrigerated storage.

5.3 Sensory evaluation

5.3.1 Colour

During the period of study colour changed according to harvest dates and different significantly at different dates. Late (H₃) and mid (H₂) harvested fruit had got maximum scores for colour (4.99) than H₁ (4.88).

After 100 days of storage apples harvested at (H₂) remained the best with respect to color scores. Late and mid harvested apples showed maximum score. The reason behind may be the synthesis of anthocyanins upto the later stages of maturity.

Among different treatments T₁ recorded the minimum values for colour whereas T₅ (Hydrocooling + CaCl₂ + Wax) received the higher values. This might be due to negative effect of hydrocooling, CaCl₂ and wax coating on senescence of fruit. Coating materials have been reported to maintain the skin colour (Habibunisa *et al.*, 1988).

As it is clear from the Table-21 that with the prolonged storage there is considerable decrease in colour. These results are in conformation with Mir *et al.* (2004).

5.3.2 Texture

Texture scores change according the harvest dates and differ significantly at different harvest dates. Late harvested (H₃) fruits had lower sensory texture (4.79) than H₂ (4.90) and H₃ (5.00). After 100 days of storage apples harvested at H₁ retained best texture. Late harvested fruits had shown lower sensory texture at harvesting time and at the end of storage period (Kvikline *et al.*, 2008). The reason behind the higher values of texture in H₁ might be due to the higher level of calcium pectate and slow activity of pectic enzymes.

Among different treatments T₁ (control) recorded the minimum score while maximum texture score was recorded in case of T₅ (hydrocooling + CaCl₂ + wax). This might be due to the fact that all the combined treatments (hydrocooling

+ CaCl₂ + wax) applied had negative effect on the pectin degrading enzymes. Moreover calcium chloride is best known for its texture enhancing function. As it is evident from the Table-22 that with the advancement of storage there is decrease in texture score. Mir *et al.* (2004) reported similar findings while working with storage studies of apple.

5.3.3 Flavour

There was a significant effect of harvest dates on flavor scores of apple. Early harvested (H₁) fruits had lower scores for flavor (4.57) than mid and later harvested apples i.e. H₂ (4.90) and H₃ (4.77). After the storage period apples harvested at mid i.e. H₂ got the maximum score for flavor after the storage. The reason behind the maximum score for H₂ fruits might be due to balance sugar acid ratio and the reason behind the lowest score for H₁ might be less sugar and aroma compounds.

Among different treatments T₅ (hydrocooling + CaCl₂ + wax) recorded the maximum score for flavor. While as T₁ (shade cooled) received the minimum scores. These results are in accordance with Mir *et al.* (2004). The reason behind the maximum scores for T₅ (hydrocooling + CaCl₂ + wax) might be due to less moisture loss which results in maintenance of balanced sugar acid ratio due to less pronounced biochemical reactions.

As it is clear from the Table-23 there was continuous decrease in flavor scores with the advancement of storage (Habibunisa *et al.*, 1988).

5.3.4 Overall acceptability

During study overall acceptability changed according to harvest dates and differed significantly at different dates. Late and early harvested apples i.e. H₃ and H₁ and shown lower values for overall acceptability (4.90) while as mid harvested apples (H₂) got maximum score (5). After 100 days of storage apples harvested at H₂ retained the best quality. Late harvested fruits had shown lowest scores at the time of harvest and at the end of storage period. The lower values of overall

acceptability in H₁ may be due to the lower content of sugars and aroma and in late harvested apples may be due to higher sugar and less firmness (Hussain *et al.*, 2012).

Among different treatments T₁ (control) recorded the minimum and T₅ (hydrocooling + CaCl₂ + wax) recorded the maximum score. The reason behind this might be due to synergistic effect of treatments on delaying the process responsible for the decaying, solubilization of pectin and loss of moisture and volatiles (Hayat *et al.*, 2003).

As it is depicted in Table-24, with the advancement of storage period there is a decrease in overall acceptability. This decrease in overall acceptability might be due to the loss of moisture, increase in sugars, decrease in firmness and volatiles (Sud *et al.*, 1992).

5.4 Economic feasibility estimation

During the analysis of “Red Delicious” apple for economic feasibility, significant differences were observed at different time intervals during the storage period on returns to treatment. The highest mean value of 3.40 and 4.90 in harvest date second (H₂) for treatment T₅ (hydrocooling + CaCl₂ + wax) under ambient and refrigerated conditions, respectively. The reason behind the higher returns to treatment might be due to the effect of different treatments and harvesting stage to retain maximum quality attributes.

As it is evident from the data presented in Table-25 there was a continuous increase in returns to each rupee invested through the storage period of 100 days. The reason might be the non-availability of produce/fruit during off season. Treatment T₅ (hydrocooling + CaCl₂ + wax) proved most viable returning treatment to producers.

Chapter – 6

SUMMARY AND CONCLUSION

The experiment on “Effect of harvest dates and postharvest treatments on quality and shelf life of stored apple cv. “Red Delicious” was carried out at Department of Postharvest Technology SKUAST-Kashmir, Shalimar, Srinagar, Jammu and Kashmir during 2011 and 2012. Fruits were procured from the orchard of Mohd Afzall Ganaie Shadimarg Pulwama, 40 kilometers from Srinagar. These were harvested at three stages of harvest maturity at seven days interval representing early (H_1) mid (H_2) and late (H_3) harvesting stages.

Fruit length differed significantly at different dates of harvest. The highest mean maximum fruit length of 74.21 mm was observed in mid harvested apple (H_2) at zero day of storage. Treatments showed a positive effect on retention of fruit length. The highest fruit length of 70.36 mm was recorded in T_5 (hydrocooling + $CaCl_2$ + wax). Storage showed a considerable effect on fruit length. The mean fruit length after the end of storage period was 62.26 mm under ambient and higher under refrigerated storage.

Harvest dates showed a significant effect on fruit diameter, fruit diameter varied with the harvest date. The maximum fruit diameter of 67.35 mm was showed by harvest date 2nd (H_2) at zero (0) days of storage. All the treatments proved to be the effective in retaining fruit diameter. Among treatments T_5 (hydrocooling + $CaCl_2$ + Wax) recorded the maximum fruit diameter of 62.13 mm. At the end of 100 days storage period the mean maximum fruit diameter of 52.68 mm was recorded under ambient and increased values were recorded in refrigerated environment.

Mean maximum L/D ration of 1.08 was recorded in late harvested apples (H_3) at zero days of storage.

All the postharvest treatments applied remained best to retain L/D ratio but the highest L/D ration of 1.12 was recorded in T_5 (hydrocooling + $CaCl_2$ +

Wax). There was continuous increase in L/D ratio. The mean maximum L/D ratio of 1.15 was recorded at the end of storage under ambient condition.

Harvest dates showed significant effect on fruit weight and differed with different date, maximum fruit weight of 166.40 (g) was recorded in late harvest apples (H₃) at zero (0) days of storage. Postharvest treatments proved best to retain fruit weight. The highest fruit of 164.53 (g) was observed in treatment T₅ (hydrocooling + CaCl₂ + Wax). Fruit weight decreased significantly during the storage maximum fruit weight recorded at the end of 100 days of storage was 160.87(g) under ambient conditions but higher in refrigerated.

Fruits of “Red Delicious” apple showed significant response to maturity stage. The maximum fruit firmness of 19.70 lb/inch was exhibited by early harvested fruit (H₁) at zero (0) day of storage. Among treated fruits treatment T₅ (hydrocooling + CaCl₂ + wax) recorded the maximum firmness value of 17.00 lb/inch² under ambient conditions.

Decreased firmness was observed in all treatments and harvest dates during storage, however the decrease were more in ambient than refrigerated storage. The highest value for fruit firmness recorded was 13.23 lb/inch² at the end of storage under ambient conditions.

Harvest maturity showed significant effect on Lab values. The mean maximum L* value of 40.60 was observed in H₁ whereas maximum mean value of 31.72 for a* was recorded in H₃ and the maximum mean value of 16.90 for b* was recorded in harvest date H₁. Postharvest treatments proved best to retain LAB values. Among treatments the highest value of L* 43.04 was observed for T₁ (Control). Whereas maximum a* value of 30.03 was recorded in T₅ (hydrocooling + CaCl₂ + wax) and the maximum b* value of 18.37 was recorded in treatment T₁ (Control).

There was significant increase in L* and b* values during storage. The maximum values of 38.00 and 20.85 were recorded for L* and b* at the end of

storage respectively whereas the maximum a^* value record after the end of storage was 27.01 under ambient conditions. The values were different under refrigerated storage.

The mean maximum rot incidence (0.00%) was observed for all the harvest dates at the 0 day of storage. Postharvest treatments showed significant effect on rot incidence. The highest percentage rot incidence of 1.57 was recorded in early harvested fruits (H_1). Rot incidence increased during the storage. The maximum rot incidence of 3.86 per cent was recorded at the end of storage period of 100 days under ambient period and under refrigerated incidence was much less.

The mean physiological weight loss of 0.00 per cent was observed in all harvest dates at zero day of storage. Treatments proved effective to retain moisture content of "Red Delicious". The mean maximum weight loss of 8.74 per cent was observed for treatments T_1 (control).

Continuous weight loss was recorded during the storage loss was less in refrigerated storage than ambient. Maximum mean PLW of 16.55 per cent was recorded after the storage under ambient conditions.

Harvesting stage showed a significant effect on moisture content of "Red Delicious" Apple the mean maximum moisture content of 82.60 per cent was recorded in early harvested fruits (H_1) at 0 day of storage. Among treatments T_5 (hydrocooling + $CaCl_2$ + wax) recorded the mean maximum moisture content of 75.13 per cent. Moisture decreased during the whole storage period the loss was more pronounced in ambient than refrigerated storage. The maximum value of 65.98 per cent for moisture was recorded after 100 days of storage under ambient conditions.

The effect of harvest dates was significant during storage on "Red Delicious" apple.

The highest Total Soluble Solid (TSS) was found in H_3 (14.54 %) at 0 day of storage. Among the treatments T_1 (control) showed the maximum TSS of 16.91

per cent in harvest date (H₃). After the 100 days of storage under ambient environment the maximum mean value of TSS increased upto 17.92 per cent. However the values were much more lower in refrigerated storage than that of ambient.

Significant effect of harvest maturity on acidity of “Red Delicious” apple were observed under ambient storage. The maximum acidity of 0.363 per cent was recorded in early harvested fruit (H₁) at 0 day of storage. Treatments also showed significant impact on total acidity. T₅ (hydrocoolig + CaCl₂ + wax) showed maximum acidity of 0.335 per cent under ambient storage. At the end of storage, the acidity decreased up to 0.239 per cent. However under refrigerated storage the higher values of acidity were observed.

At different stages of maturity the per cent total sugar differed significantly. The highest total sugar of 10.26 per cent was observed in late harvested apples (H₃) at 0 days. All treatments showed significant effect on total sugars. The highest total sugars was recorded for the treatment T₁ (13.03) there was continuous increase in total sugar during storage. The highest value of 13.75 per cent was recorded after the end of storage period. The increase was less pronounced under refrigerated conditions.

Harvest maturity showed significant effect on juice content of “Red Delicious” apple. The highest juice content of 59.50 per cent was recorded in mid. Harvested apples (H₂) at zero day. Among the treatment maximum juice content of 50.33 per cent was recorded in T₅ (hydrocoolig + CaCl₂ + wax). There was significant decrease in juice content under ambient than refrigerated environment at the end of storage. The juice content decreased up to 37.24 per cent under ambient conditions.

Calcium content of “Red Delicious” apple showed a slight difference with respect to harvest maturity. The maximum calcium content of 6.90 (mg/100g) was recorded in early harvested apple (H₁). Post harvested treatments showed a

significant effect on calcium content of fruit. The highest mean value of 7.05 (mg/100g) calcium content was recorded in treatment T₅ (hydrocoolng + CaCl₂ + wax). There was significant increase in calcium content in fruit during storage but increase was less in refrigerated storage. The highest value of 7.05 (mg/100g) Calcium was observed at the end of 100 days of storage under ambient conditions.

Significant effect of harvest maturity was observed on pectin content of apple. The mean maximum pectin content of 1.61 per cent was recorded in early harvested apple (H₁) at the 0 day storage. Among the all treatments T₅ (hydrocoolng + CaCl₂ + wax) showed the maximum pectin content of 1.23 per cent there was significant decreases in pectin under ambient storage. The maximum mean value of 0.62 per cent was recorded at the end of storage period. The figures were on higher side under refrigerated environment.

Anthocyanin content of “Red Delicious” apple changed significantly with harvest maturity. The maximum anthocyanin content of 33.30 (mg/100g) was observed in late harvested fruit (H₃) at 0 days of storage. Treatments showed a significant effect on total anthocyanin content. Among the treatments T₅ (hydrocoolng + CaCl₂ + wax) recorded the maximum anthocyanin content of 31.68 (mg/100g). During storage there was decline in anthocyanin content. The highest decline was recorded under ambient storage than refrigerated .The mean value of 28.05 (mg/100g) C was observed at the end of storage under ambient environment.

Ascorbic acid content of “Red Delicious” apple showed significant correlation with harvest maturity. The maximum ascorbic acid content of 12.50 (mg/100g) was recorded in late harvested fruit (H₃) at 0 day storage. All the treatments showed a significant effect on ascorbic acid content. Among the treatments T₅ (hydrocoolng + CaCl₂ + wax) showed the maximum ascorbic acid content of 9.48 (mg/100g). Ascorbic acid showed a significant decrease during storage. The maximum ascorbic acid content of 4.47 (mg/100g) was observed

under ambient conditions. Higher values were recorded under refrigerated conditions at the end of storage period.

Polyphenol content differed significantly at different harvest dates. The highest value of polyphenol content (mg/100g) was found in early harvested apple (H₁) at zero day storage. Treatments showed a significant effect on polyphenol content. The value of 2.65 (mg/100g) was observed in Treatment T₅ (hydrocooling + CaCl₂ + wax). Continuous decreases in polyphenol content was recorded during storage. The decrease was more prominent in ambient than refrigerated storage. The highest value of 2.42 (mg/100g) was recorded after the 100 days of storage under ambient environment.

“Red Delicious” apple showed a significant differences in pectin methyl esterase activity with respect to harvest maturity. The highest pectin methyl esterase activity of 31.27 was observed in late harvested fruits (H₃) at zero day storage. Postharvest treatments showed a significant effect on pectin methyl esterase activity. Pectin methyl esterase activity of 42.17 was recorded in T₅ (hydrocooling + CaCl₂ + wax). There was continuous increases in pectin methyl esterase activity during storage, the increase was more in H₁ under both the storage conditions, however, the increase was less in refrigerated conditions. The highest value of 49.43 was found at the end of storage under ambient storage.

Polygalacturonase activity of “Red Delicious” apple differed significantly with respect to harvest dates. The highest polygalacturonase activity of 10.20 (% loss in viscosity) was observed in late harvested fruits (H₃) at 0 day storage. Treatments also showed significant effect on polygalacturonase activity. Among all the treatments T₁ (control) recorded the maximum polygalacturonases activity of 14.25 (% loss in viscosity) in late harvested (H₃) fruits. At the end of storage polygalactouronase activity increased up to 18.13 (% loss in viscosity) under ambient conditions however loss was less in refrigerated storage.

Among all the harvested dates. Harvest date 2nd (H₂) was awarded higher scores of 4.99 at the 0 day storage. Treatments showed a significant effect on sensory colour scores. Among treatment T₅ (hydrocoolng + CaCl₂ + wax) recorded the maximum mean score of 4.94. There was continuous decreases in sensory colour during storage, maximum mean score of 4.67 was recorded at the end of storage in ambient storage and higher in refrigerated storage.

Early harvest fruits (H₁) proved best in terms of sensory texture. The maximum mean sensory texture score of 5.00 was recorded in harvest date first (H₁). Among the treatments maximum beneficial effect of treatment on retention of firmness was recorded in case of T₅ (hydrocoolng + CaCl₂ + wax) and was awarded mean sensory texture score of 4.51 under ambient condition. At the end of storage period the highest mean value of 3.43 was observed under ambient however scores were higher in refrigerated condition.

The panellists awarded the maximum scores of 4.90 for sensory flavour to harvest date H₂ at zero (0) days of storage. All treatments proved to be effective in retaining flavour of fruit but panellists awarded the maximum score of 4.57 to the treatment T₅ (hydrocoolng + CaCl₂ + wax) flavour scores declined significantly with the advancement of storage decline was more in ambient than refrigerated storage. The maximum scores of 3.98 was recorded after the end of storage under ambient condition.

The overall acceptability scores on the basis of sensory colour, texture and flavour changed significantly in accordance with harvest maturity, panelists awarded the maximum score of 5.00 in case of mid harvested fruit (H₂) at zero day storage. Among the treatment T₅ (hydrocoolng + CaCl₂ + Wax) received the maximum score of 3.23 at the end of storage under ambient condition, however, the values were different under refrigerated storage.

During the analysis of “Red Delicious” apple for economic feasibility the returns to the investment differed differently with storage intervals. The highest

mean return value of 3.40 per rupee invested under ambient and 4.90 under refrigerated storage for treatment T₅ in harvest date H₂ were recorded.

CONCLUSIONS

The result of the present investigation revealed that the influence of Harvest dates on “Red Delicious” apple quality is significant. Optimum harvest maturity is essential to maintain juiciness, colour, texture, flavour and over all acceptability during the ambient as well as refrigerated storage. All the treatments showed positive effect on overall quality of “Red Delicious” apple. Among all the Treatments T₅ (hydrocooling + CaCl₂ + wax) were promising and beneficial followed by T₃ (hydrocooling + CaCl₂). The fruit quality on the basis of sensory scores was not adversely affected by such post harvest treatments under both storage conditions. All the treated fruits were maintained in good quality up to 100 days of storage in comparison to control. The postharvest treatments of “Red Delicious” thus helped to maintain the quality attributes over a span of 50 days under ambient conditions and over 100 days in refrigerated conditions without much change in sensory quality. These low cost treatments proved profitable for the persons involved in the business and enabling grower to make decisions as per the demand in market. These treatments shall prove beneficial in fetching good price of the produce.

RECOMMENDATIONS

- 1) “Red Delicious” apple has superior quality due to its high juice content, ascorbic acid and fruit flesh firmness.
- 2) Early harvested fruits (H₁) were found to have highest weight loss and least juice content, thus early harvested fruits should not be stored long.
- 3) Fruits harvested at mid (H₂) had relatively less rot incidence and maintain maximum quality attributes like firmness, pectin and acidity and are recommended for long storage.

- 4) Late harvested fruits become mealy, soft and had shown higher rot incidence and thus can not be recommended for long storage.
- 5) Refrigerated storage is far better to retain maximum quality attributes up to 6 month than ambient storage.
- 6) Effect of post harvest treatments had significant effect on retention of overall quality.

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. W.S. Dhillon, Director (Former ADG Hort. ICAR), Punjab Horticultural Postharvest Technology Centre, PAU, Ludhiana during Viva-Voce examination held on 16th of December, 2013 have been incorporated in the manuscript entitled **“Effect of Harvest Dates and Post Harvest Treatments on Quality and Shelf-life of Stored Apple cv. Red Delicious”** submitted by **Mr. Shaiq Ahmad Ganai (Regd. No. 2010-305-D)**.

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