EFFECT OF PRECOOLING AND STORAGE CONDITIONS ON FRUIT QUALITY OF NEW EXOTIC CULTIVARS OF APPLE (*Malus* × *domestica* Borkh.)

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled **"Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"** submitted in partial fulfillment of the requirements for the award of the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 is a bonafide research work carried out by **Mr Kripal Chand (H-2021-25-M)** son of Mr Prem Chand under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Nauni, Solan (HP)
Dated:

Dr Pramod Verma
Major advisor

CERTIFICATE-II

This is to certify that the thesis titled, **"Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"** submitted by **Mr. Kripal Chand (H-2021-25-M)** son of Shri Prem Chand to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) – 173 230 India in partial fulfilment of the requirements for the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Date:
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CONTENTS

ABBREVIATIONS USED

%	:	Per cent
ºB	:	Degree Brix
ºC	:	Degree Celsius
ANOVA	:	Analysis of Variance
cm	:	Centimeter
cm^2	:	Square centimeter
cc	:	Cubic centimeter
CD	:	Critical difference
CFB	:	Corrugated Fiber Board
CRD	:	Completely Randomized Block Design
cv.	:	Cultivar
df	:	Degree of Freedom
DPPH	:	2, 2-Diphenyl-1-picrylhydrazyl
et al.	:	Co- workers
g	:	gram
g/cc	:	Gram per cubic centimeter
GAE	:	Gallic Acid Equivalent
ha	:	Hectare
kg/cm^2	:	Kilogram per square centimeter
mg	:	Milligrams
MT	:	Metric Ton
NS	:	Non Significant
OD	:	Optical Density
PLW	:	Physiological Loss in Weight
TSS	:	Total soluble solids

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Chapter-1

INTRODUCTION

The apple (*Malus* × *domestica* Borkh.) is the most significant fruit crop grown in temperate regions of the world between 30° and 50° latitude in both the hemispheres (Westwood, 1993). The cultivated apple belongs to the Rosaceae family and Maloideae subfamily (Evans and Campbell, 2002) and is native to South Western Asia (Brown, 1975). In India, the total cultivable area under apple is 3,12,000 ha with an annual production of 24,37,370 MT and productivity of 7.81 MT/ha (Anonymous, 2021a). The area under apple cultivation in Himachal Pradesh is 1,14,630 ha with an annual production of 6,43,850 MT and productivity of 5.61 MT/ha (Anonymous, 2021b).

Apple being a climacteric fruit, should be harvested at proper physiological maturity to fetch high prices in the market (Roth *et al*., 2005; Sayin *et al*., 2010). In Himachal Pradesh the bulk of apple crop is harvested in the months of August and September depending upon maturity of cultivars and micro-climatic conditions of the regions. Hence, majority of apple trade dominates the entire fruit market during these months, causing glut in the market, which ultimately led to lower market prices to the farmers. In order to overcome this effect, the apple fruits needs to be cooled after harvesting and stored for longer period of time. Apple fruits are susceptible to deterioration after harvest and must be cooled as soon as possible. The first critical step after harvest is to remove field heat by cooling prior to transportation in storage (Defraeye *et al*., 2014).

Pre-cooling reduces the temperature of fruit immediately after harvest, generally reducing the respiration rate of fruits and process of senescence is retarded, ultimately accounting for better shelf-life of fruits. Delayed pre-cooling increases the loss of moisture, lowers tissue firmness and increased metabolic activities in fruits (Mahesh, 2007). Temperature control is the most used technique for post-harvest conservation of fruits (Kader, 2002; Kishor *et al*., 2018). The post-harvest losses in terms of quality and quantity occurs at various stage of fruit handling right from harvesting till the fruits reaches to the consumers (Issar *et al*., 2010). The stage at which fruits are collected determines the best fruit quality and storage behavior. Physico-chemical changes during storage of fruits are used as important criteria for determining the optimum storage period which are essential to work out

the transportation mode from one place of production to distant markets. Cooling associated with low temperature assists in the maintenance of quality during commercial handling, which allow enhancing the shelf-life of fresh fruits like apple, kiwifruits, peach, cherry, plum etc. (Chiabrando and Giacalone, 2011; Gunther *et al*., 2015).

Several pre-cooling techniques are available for fruits including hydro-cooling, forced air cooling, vacuum cooling, cryogenic cooling, air cooling and room cooling (Senthilkumar *et al*. 2015; Matouk *et al*., 2018; Sena *et al*., 2019). These methods use different modes and media for their function. Room cooling and air cooling use cold air and hydrocooling makes use of cold water, package iced products having direct contact with ice, vacuum cooling employs the evaporation of water and cryogenic cooling involves liquid nitrogen (Senthilkumar *et al*., 2015). The post-harvest behaviour of apple vary depending on various factors like cultivars, rootstocks, soil, agro-climatic conditions, growth and development pattern including flowering, fruiting, maturity, chemical composition of fruits as well as storage conditions. However, in India there is limited information on the physico-chemical changes that take place in apple while they are being stored which have been reported by various authors (Pandey *et al*., 2006; Sharma *et al*., 2009; Issar *et al*., 2010; Kishor *et al*., 2018).

In the past few years, Himachal Pradesh has introduced new apple cultivars that are flourishing in the mid-hills regions, as being early maturing and possessing good colour. Thus, there is need to assess the storage potential of these new introduced commercial cultivars for improving their shelf-life and ultimately market value. Hence, keeping in view these facts the present study was proposed on the "Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)" and carried out in the Department of Fruit Science during the year 2022, to meet with the following objectives:

i) To find out the optimum precooling conditions for apple
ii) To assess the effect of storage conditions on fruit quality of apple

Chapter-2

REVIEW OF LITERATURE

Apple is one of those fruit crops whose quality changes rapidly during storage period, due to which its acceptability among consumers also varies (Johnston *et al*., 2001; Vieira *et al*., 2009; Ahmad *et al*., 2021). Precooling in association with low temperature storage assists in maintenance of post-harvest attributes and enhancing shelf-life of fruits (Günther *et al*., 2015; Yan *et al*., 2017). A comprehensive review on effect of different precooling methods and storage conditions on post-harvest fruit quality have been reviewed under following sub-heading.

2.1 Effect of different precooling methods on fruit quality

Billiard **(**1999) while investigating different techniques and equipment employed in fruit cold storage observed that different precooling techniques and refrigerating systems, lead to better maintenance of organoleptic qualities, reduced spoilage and enhanced shelf life of fruits. Garg *et al*. (2003) studied the effect of various postharvest treatments on the storage quality of peach cv. July Elberta. Fruits were analysed for various physico-chemical characters like physiological loss in weight (% PLW), fruit firmness, total soluble solids, total sugars, reducing sugars, titratable acidity, total ascorbic acid contents and spoilage. They observed that precooled fruits showed less firmness loss, less spoilage, little change in titratable acidity, and an increase in soluble solids and total sugars. The rate of physico-chemical changes was generally reduced by precooling in combination with waxing, and after four weeks of storage, precooled fruits coated with 100 per cent Sta Fresh- 960 maintained their best quality.

Kim *et al*. (2003) conducted a study on the effects of precooling treatments on the quality of peaches (Mibaek). In this study, a pressure cooler was used to cool the peaches from 25.9°C to 5°C in 3 hours, and the cooling rate was accelerated by increasing air velocity and static pressure. They found that in Mibaek peaches respiration and ethylene production rates were approximately four times faster at 20°C than at 7°C. Precooled peaches had better visual quality, less weight loss, higher soluble solid and ascorbic acid content than non-precooled peaches.

Akbulut and Özcan (2005) while studying the effects of various precooling applications on postharvest quality of ‘0900 Ziraat' sweet cherries, concluded that the precooling with water is 13 times faster than the precooling with air. Precooling applications reduced quality losses. '0900 Ziraat' performed well upto 3-4 weeks in storage conditions. Although the flavour and quality of the fruit began to deteriorate by the third week, they were still of saleable quality by the fourth week. They further observed that the skin color and stem darkened by the end of storage period. Silva *et al*. (2006) compared the performance of forced air cooling and water cooling for apples. Two lab-scale precooling systems were built to allow a comparison. They concluded that water cooling is approximately twice as fast as air cooling.

Manganaris *et al*. (2007) studied the effect of hydrocooling on ripening related quality attributes and cell wall physico-chemical properties of sweet cherry fruit (*Prunus avium* L.). The objective of this study was to determine how hydrocooling, a precooling method, affected ripening-related parameters in two sweet cherry cultivars (*Prunus avium* L. cvs. "Tragana Edessis" and "Mpakirtzeika") after a week of cold storage (0°C, 95% R.H.). Cherry fruit deterioration and senescence were delayed by hydrocooling, maintaining a better quality, as indicated by reduced stem browning and surface shrivelling. Hydrocooled 'Tragana Edessis' fruit, showed significantly less stem browning (14.6-29.6%), than ‘Mpakirtzeika’ fruit. Hydrocooling had no effect on other quality characteristics like cracking, decay, external color, or soluble solids content. Overall, the results of the study demonstrated that cherry fruit subjected to hydrocooling and then stored for a week at 0°C and 95% R.H. maintained their quality for a further three days at room temperature, but many of the fruit were of unacceptable quality after five days at room temperature.

Li *et al*. (2011) investigated the effects of precooling temperatures (-3°C, -5°C and -10°C) on storage qualities of refrigerated and shelved ‘Angeleno’ plum fruits. Their results showed that the precooling at -10°C could reduce fruit pulp temperature to 1°C which slow down the decrease of firmness and titratable acid content of shelved fruit, and significantly reduce the rot rate of refrigerated and shelved fruits when compared with control. Fruits precooled at -3°C could also keep the qualities of refrigerated and shelved fruits to some extent. Precooling at -5°C caused chilling injury. The precooling temperature for plum fruit was suggested to be -10°C due to the extensive effects of precooling temperatures on the qualities of refrigerated and shelved plum fruits.

Diaz-Mula *et al*. (2013) while studying the effect of precooling application before cold storage on shelf life and quality of Sweet Cherry 'Sonata' observed that the quality parameters (weight loss, total soluble solids, acidity, firmness and colour) shows an accelerated changes in control (no-precooling) than the pre-cooled fruits. They further concluded that pre-cooling treatment before cold storage could be a useful tool for delaying the postharvest ripening process of sweet cherry and thus extending the storability of this perishable fruit. They also observed that pre-cooled cherries had higher antioxidant activity in both hydrophilic and lipophilic fractions at the end of storage than control fruits.

Ganai *et al*. (2015) studied about the colour changes during storage of apple cv. Red Delicious, as influenced by the harvesting dates, precooling, calcium chloride and waxing treatment. The color change was evaluated by sensory analysis, L*, a*, b* values using chromometer and anthocyanin content. 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. They observed that during storage, there was colour degradation as indicated by an increase in L* and b* values and a decrease in a* values. The treatment Hydrocooling + $CaCl_2$ + wax resulted in least changes in all of the studied parameters, whereas, treatment shade cooling exhibited the most changes.

Jawandha *et al.* (2016) investigated the effect of pre-cooling on storage behaviour of peach "Shan-e-Punjab". Two methods of pre-cooling (Forced air cooling and hydro-cooling) were used. Pre-cooled fruits were placed in CFB boxes and kept in storage for 35 days at 0-1°C and 90-95% RH. Pre-cooled fruits were examined for 5 weeks at 7 days intervals for various physico-chemical properties. They concluded that at the end of the storage, the fruits that had been precooled using forced air cooling had minimal physiological weight loss, no spoilage, and highest firmness, sensory quality rating, and acidity.

Yan *et al*. (2017) evaluated the effects of forced-air precooling on fruit quality and antioxidant activity of apricot. Apricots were forced-air precooled at 0°C for 24 hours before being stored at 0°C for up to 20 days. They found that the precooling treatment slowed the rate of decrease of titratable acidity (TA) and total soluble solids (TSS) content during storage. Further they observed that pre-cooled fruits had 73.60 per cent higher DPPH than the control on the 15^{th} day of storage and concluded that precooling treatment could maintain the quality of apricot by enhancing antioxidant activity.

Matouk *et al.* (2018) studied the pre-cooling and temporary storage of apple fruits. They compared the non-precooled fruits with the precooled fruits during temporary storage process under cool storage condition. The fruits were subjected to three levels of water temperature (3, 5 and 8°C), three levels of water flow rate (5, 8 and 11 L/min), and two volumes of fruits (medium and large). The results showed that the apple temperature dropped rapidly at the start of the cooling process and the cooling rate began to slow as the product temperature approached the temperature of the cooling water. The values of cooling coefficient (C) increased with the decrease of fruit volume and cooling water temperature, and with the increase of water flow rate. The half and seven-eighth cooling times decreased as water flow rate increased, while increased as water-cooling temperature and fruit volume increased. The storage experiments showed that, the pre-cooled apple fruits recorded lower loss in moisture, lower total soluble solids, higher fruit firmness and higher total sugar content compared with the non-precooled fruits.

Carnelossi *et al*. (2019) compared the cooling efficiency of conventional forced-air cooling (FA) with immersion hydro-cooling (HY) alone or in combination on blueberry fruit quality during subsequent cold storage. They observed that hydro-cooling had the potential to rapidly and thoroughly cool southern highbush blueberries like 'Farthing,' preserving fruit quality by introducing a rinsing and sanitizing treatment. After 21 days, cooling method did not affect fruit firmness of cv. ‘Farthing’. After 14 days of storage, 'Emerald' apple fruit cooled by HY+FA were softer than those cooled by HY or FA. Anthocyanin concentration in 'Emerald' fruit from the HY + FA cooling method decreased by 33% during 21 days of storage, whereas it remained constant in 'Farthing' regardless of treatment during storage (8.3 mg cyanidin-3-Glicoside/g).

Lomeiko *et al*. (2019) conducted a study on the vacuum cooling technology for pre-cooling of cherry fruits. They observed that the duration of short-term storage of cherry fruit was extended by 7 days due to vacuum cooling. In addition, the fruits have a higher commercial quality, with respect to titrated acids (1.69-3.07 %), total sugars (3.4-9.21 %), vitamin C (42.00 %) after the usual cold storage. The total organoleptic evaluation of the fruit after vacuum cooling was 34.00 per cent higher than the control variant. Thus, they concluded that vacuum cooling is a fast and effective method for cooling cherry fruit as compared to conventional refrigeration.

Sena *et al*. (2019) studied the postharvest quality of cashew apple after hydro-cooling and cold room storage. They reported that the cashew apple fruits showed greater freshness, firmness and acidity, and slower losses of fresh weight and vitamin C with hydro-cooling when compared with cold room. They futher observed that the total phenolic contents decreased while the red colour loss of the cashew apples was constant during storage.

Park *et al*. (2020) conducted a study on pre-cooling and storage behaviour of strawberries cv. 'Maehyang'. Strawberries fruits were precooled to 0, 2 and 4°C for 3 hours in the cold store and then stored at low temperature in the cold store set at 4, 8 and 10°C storage temperatures. The weight loss rate, firmness, soluble solids content, color and incidence of gray mold of strawberries were measured at two days intervals during storage for 14 days. They concluded that the Strawberry cultivar 'Maehyang' stored at 4°C after precooling at 0°C maintained the best shelf life and fruit organoleptic parameters.

Mahajan *et al*. (2022) evaluated the effect of different precooling methods such as Hydro-cooling (HC), Forced air cooling (FAC) and Evaporative cooling (EC) on post-harvest quality of pear fruit under cold storage conditions. In all the precooling methods, a digital thermometer was used to monitor the temperature of fruit pulp until a steady temperature (5.2°C) was achieved. After giving the precooling treatments, the fruits were packed in corrugated fibre board boxes and stored in cold room (0–1°C and 90–95 % relative humidity). The stored samples were evaluated periodically at 15 days intervals up to 75 days for physico-chemical quality attributes. Their results indicated that the FAC (Forced Air Cooling) maintained lower physiological weight loss (3.51 %) and decay (3.00 %), retained higher firmness (13.67 lb force), organoleptic score (7.52 out of 9), TSS (12.52 °B), total sugars (8.05 %), acidity (0.27 %) and total phenols (39.28 mg GAE/100g) during storage as compared to control.

Mahajan *et al*. (2023) also studied the effect of different precooling methods on shelf-life of pear (*Pyrus* spp.) fruits under ambient storage. The fruit were subjected to 3 methods of precooling viz. Hydro-cooling (HC), Forced Air Cooling (FAC) and Evaporative Cooling (EC). They concluded that the forced air cooling (FAC) showed lower physiological weight loss and spoilage, while maintaining higher fruit firmness, sensory quality score, juice TSS, total sugars, acidity, vitamin C, and total phenolic content in comparison to the control (no-precooling).

2.2 Effect of different storage conditions on post-harvest fruit quality

Burda *et al.* (1990) while studying about the phenolic compounds and their changes in apples during maturation and cold storage observed that the concentration of individual phenolics in apple flesh decreased sharply during the early stage of development and then remained relatively constant during maturation and storage. Further, Perez-Ilzarbe *et al.* (1997) also conducted a study on cold storage and changes in phenolic compounds of apples cv. Granny Smith. The fruits harvested at commercial maturity were stored at 4°C for 10 days before being rewarmed at 22°C to test the effect of cold storage on phenolic content. They found that the behaviour of phenolic compounds was different in peel and pulp. Apple phenolic compounds in the pulp decreased during the development period and during the cold treatment. The amount of phenolic compounds in the peel increased with time after cold treatment, reversing their normal behaviour during the development period.

Johnston *et al*. (2001) examined the physical change in apple texture with change in fruit temperature. Apple fruit from Royal Gala, Granny Smith, and Pacific Rose was kept at 0°C, while 'Cox's Orange Pippin' was kept at 3°C. They discovered that Royal Gala, Granny Smith, and Cox's Orange Pippin fruit had higher firmness readings at harvest when measured at 20°C than at 0-3°C, but firmness and tensile strength readings at 0-3°C were greater after 50-100 days. When measured at 0°C and 20°C, Pacific Rose had similar firmness and tensile strength readings.

Leja *et al*. (2003) studied the antioxidant properties of two apple cultivars (Jonagold and Sampion) during long-term storage. The antioxidant capacity of the peel of two apple cultivars (Jonagold and Sampion) stored for 120 days at 1°C in the regular cold chamber or in CA (2 % CO_2 / 2 % O_2) was determined. They found that the total phenols and total antioxidant activity (TAA) increased significantly during long-term cold storage as well as an additional 7 days storage of fruits at 16°C, regardless of storage conditions. A slight decrease in anthocyanin content was observed in apples stored in air, while the CA treatment had no effect.

Ali *et al*. (2004) conducted a study on the effect of different periods of ambient storage on chemical composition of apple fruit. The experiments were conducted on five apple varieties, namely Golden Delicious, Mashhadi, King Ambri, Kalakulu and Ambri to study the effect of ordinary storage at room temperature (25°C) for two weeks during the month of September. The chemical analysis consisted of sugars, acidity, total soluble solids

and ascorbic acids. They found that when the storage period was extended, reducing sugar increased, non-reducing sugar decreased and total sugars of all varieties increased. During storage of the five varieties at room temperature, a non-significant decrease in acidity and a significant increase in total soluble solids were observed. Vitamin C decreased during storage. They conclude that 'Ambri' and 'Golden Delicious' cultivars of apple can be stored up to six weeks to fetch good market price.

Pandey *et al*. (2006) studied the storage behaviour of apple cultivars under ambient storage condition (15 to 20 ± 2°C and 75 ± 5% RH). They observed a gradual decrease in fruit firmness during the first 14 days of storage, but after that there was a significant reduction in fruit firmness due to tissue softening, particularly in Starkrimson and Gold Spur. After 7 days, total soluble solids levels increased rapidly in all cultivars, with Starkrimson showing a significant increase in TSS content that lasted for the remaining 14 days of storage. After 21 days of storage, the levels of reducing sugars in Gold Spur, Oregon Spur, and Starkrimson increased dramatically. Changes in non-reducing and total sugar levels were also rapid in all cultivars. However, the increase was more pronounced after 28 days of storage in Hardi Spur and Gold Spur. In all the cvs., ascorbic acid and acidity contents decreased rapidly for the first 14 days of storage and then remained constant for the next 35 days.

Khorshidi *et al*. (2010) while studying the storage temperature effects on the postharvest quality of apple, concluded that the storage with 0°C could maintain better fruit quality. The apple fruits cv. Red Delicious were stored under three different temperatures (0, 5 and 12°C). After one month, the diameter, length, volume, weight, firmness, total titrable acids (TTA), total soluble solids (TSS), marketable quality and colour surface were measured. Their results showed that, as the storage temperature increased, the diameter, length, and volume decreased. Fruits stored at 12°C lost significantly more diameter, length, and volume than those stored at 0°C or 5°C. With increasing storage temperature, the weight loss percentage increased gradually. Fruits stored at 0°C and 5°C did not loose weight significantly, but fruits stored at 12°C did loose weight significantly. The fruits stored at 0°C had highest firmness, while the fruits at 12°C had lowest firmness. The lowest TSS (8.00 %) and TTA (0.33 %) were associated with fruits stored at 12°C, while the highest TSS (9.00 %) and TTA (0.53 %) were associated with fruits stored at 0°C. The storage temperature had little effect on the surface colour of the fruits, but increased temperature reduced the marketable quality of the fruits.

Jan and Rab (2012) studied the influence of storage duration on physico-chemical changes in fruit of different apple cultivars. The fruits of Royal Gala, Mondial Gala, Golden Delicious and Red Delicious were harvested at optimum maturity and stored in cold storage for 0, 30, 60, 90, 120, and 150 days. The percent weight loss, total soluble solids and total sugar increased as storage duration increased, whereas juice content, titratable acidity, ascorbic acid, firmness and density of fruit decreased. Apple cultivar Red Delicious had the highest juice content (58.47 %), ascorbic acid (13.12 mg/100g), fruit firmness (5.98 kg/cm^2), fruit density (0.82 g/cm^3) and the lowest weight loss (2.22%). According to their findings, apple cultivar Red Delicious had good quality attributes, whereas cultivar Royal Gala had the lowest incidence of bitter pit during long-term storage.

Rab *et al*. (2012) evaluated the physico-chemcial quality of apple cv. Gala Must fruit stored at low temperature. The apple cultivar "Gala Must" was stored at 10 ± 2°C and 80-85 per cent relative humidity for 30 days before being evaluated for physicochemical quality and attributed at 30, 60, 90, 120, and 150 days. Apple storage resulted in an increase in the rate of weight loss with increasing storage duration, with 120 days resulting in the greatest weight loss (1.24 %). The flesh firmness decreased from a maximum of 7.03 kg/cm^2 in fresh fruits to a minimum of 4.31 kg/cm^2 after 150 days of storage. The total soluble solids content of fresh fruits increased with storage duration, from 17.00 % to 19.06 % after 150 days. The fruit per cent reducing sugars increased from 3.47 to 3.68 and 10.0 to 11.93 when storage was extended from 0 to 150 days, respectively, but the non-reducing sugars declined significantly from the maximum of 3.20 % to the minimum of 1.45 % during the storage for 150 days. Organoleptic quality testing revealed that different quality attributes such as taste, colour and texture deteriorated with storage, resulting in a lower overall acceptability score of 7.23 in fresh fruits and, 6.56 after 120 and 150 days, respectively. Vanoli *et al*. (2014) characterized the texture of different apple cultivars during storage through mechanical, sensory and optical properties. They noticed that W1 apples had a very firm texture, the highest sensory firmness, crispness, and juiciness scores, and the highest μa670 values. W3 apples, on the other hand, had a soft texture, were rated as the most mealy and least firm, juicy and crispy, and, had the lowest μa670 values and the highest scatterer density.

Diaz *et al*. (2017) investigated the effect of low oxygen treatment prior to cold storage on the quality of apples. They observed that combining different Low Oxygen Treatment (LOT) conditions with Dynamic Controlled Atmosphere (DCA) storage technology improved

apple shelf life. After 100 days of storage, the application of a low oxygen treatment for 10 days at room temperature was effective in maintaining destructive and non-destructive firmness, with only a minor effect on the other quality parameters.

Sumedrea *et al*. (2018) conducted a study on the influence of different storage methods on chemical properties of different apple cultivars (Idared, Goldrush, Florina, Pinova, Dalinette, Golden Reinderes, Golden Lassa and Ariane). They observed that the ascorbic acid (Vitamin C) content of fruits decreased with storage time, dropping from 10.64 mg/100g after 3 months to 9.88 mg/100g after 4 months and 9.24 mg/100g after 5 months. Total titrable acidity (TTA) decreased slightly with increasing storage period, from 0.37 per cent after 3 months to 0.34 % after 5 months. During storage, starch hydrolysis in sugars continues, resulting in an increase in total sugars. The Pinova and Dalinette cultivars had the highest total sugar content (TSC), which were significantly higher from the other studied cultivars.

Bezdadea-catuneanu *et al*. (2019) conducted a study on biochemical comparison of different cultivars of apple during postharvest storage in controlled atmosphere conditions. They compared the postharvest biochemical changes of four apple varieties ('Topaz,' 'Redix,' 'Florina,' and 'Rubinola') during storage in controlled atmosphere conditions in two different years. They analyzed that the ascorbic acid content decreased in both years of analysis. The polyphenol content of 'Topaz,' 'Florina,' and 'Rubinola' varieties increases after one year of storage due to a slowdown in metabolic processes.

Ahmad *et al*. (2021) assessed the postharvest quality assessment of apple during storage at ambient temperature. Using well-defined procedures and techniques, the physical and chemical quality attributes of apples were measured experimentally during storage after harvesting. In terms of measured quality attributes, overall quality index (OQI) models were developed. They reported that the firmness (F) and total soluble solids (TSS) ranged from 11.88 ± 0.25 to 7.68 ± 0.24 N (Newton) and 14.1 ± 0.1 to 12.7 ± 0.1 °Brix, respectively, while acidity and density ranged from 0.163 ± 0.003 to 0.081 ± 0.001 per cent and 0.995 ± 0.003 to 0.951 ± 0.004 gm/cm^3, respectively.

Lu *et al*. (2021) examined the effects of postharvest storage conditions on the fruit quality of a new red-fleshed apple cultivar (‘Meihong’). Mature 'Meihong' and 'Golden Delicious' apples were subjected to room temperature, low temperature and low temperature

with 1-MCP treatments, after which several fruit characteristics (firmness, ethylene release rate, relative content of aroma components, phenolic compounds and antioxidant capacity, fruit softening-related enzyme activities, and related gene expression) were assessed. During storage, the ethylene release rate in 'Meihong' fruits was lower than that in 'Golden Delicious' fruits. They found that the, 'Meihong' fruits were better suited to storage. Low-temperature storage with and without 1-MCP delayed fruit softening, reduced ethylene release rate and ester aroma component content, and preserved total flavonoid and anthocyanin contents. As a result, storing the fruit at low temperatures with 1-MCP or other preservatives may be beneficial in maintaining the 'Meihong' fruit quality.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled "**Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"** was carried out during the year 2022 in the Department of Fruit Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.). The details of the methodologies employed for the studies have been described briefly under following heads: -

3.1. DETAILS OF TREATMENTS

3.1.1. Experiment No I: Effect of different precooling methods on the storability of apple cv. Jeromine.

- **Treatment I (Precooling methods – P)**
  - P_1: Control (no pre-cooling)
  - P_2: Field cooling (shade)
  - P_3: Hydro-cooling (cold water)
  - P_4: Air cooling
- **Treatment II (Storage days – D)**
  - D_1: 0 day
  - D_2: 7 days
  - D_3: 14 days
  - D_4: 21 days
  - D_5: 28 days

Treatment Combinations (P x D = 20)

$P_1 D_1$	Control + 0 days
$P_1 D_2$	Control + 7 days
$P_1 D_3$	Control + 14 days
$P_1 D_4$	Control + 21 days
$P_1 D_5$	Control + 28 days
$P_2 D_1$	Field cooling + 0 days

$P_2 D_2$	Field cooling + 7 days
$P_2 D_3$	Field cooling + 14 days
$P_2 D_4$	Field cooling + 21 days
$P_2 D_5$	Field cooling + 28 days
$P_3 D_1$	Hydro-cooling + 0 days
$P_3 D_2$	Hydro-cooling + 7 days
$P_3 D_3$	Hydro-cooling + 14 days
$P_3 D_4$	Hydro-cooling + 21 days
$P_3 D_5$	Hydro-cooling + 28 days
$P_4 D_1$	Air cooling + 0 days
$P_4 D_2$	Air cooling + 7 days
$P_4 D_3$	Air cooling + 14 days
$P_4 D_4$	Air cooling + 21 days
$P_4 D_5$	Air cooling + 28 days

Treatment Combinations	:	20
Replications	:	3
Design	:	CRD (Factorial)
Cultivar	:	Jeromine

3.1.1.1. METHODOLOGY

The uniform size and mature fruits harvested on 25/7/2022 of cultivar Jeromine / M 9 were collected and subjected to different pre-cooling treatments (Field Cooling, Hydro-cooling, and Air-cooling) and further stored under normal room temperature (20-22° C) for 28 days.

3.1.1.1.1. Precooling Time

The initial fruit pulp temperature on fruit tree was measured with digital ELMEIRON IP67 thermometer PT-105 caliberated to the nearest (± 0.15° C). The thermocouples were inserted into the fruits from four different directions and average temperature was calculated and considered as initial temperature prior to pre-cooling (Plate 1). In Hydro-cooling treatment, the fruit pulp temperature was regularly estimated till the fruit pulp temperature was attained half cooling time ($TAT_{1/2}$) (Teruel *et al.,* 2004). The half cooling time ($TAT_{1/2}$)

Plate 1. Initial fruit pulp temperature recorded at field condition by fruit thermometer.

was calculated by using the formula : $TAT_{1/2}= \frac{Tp - Ta}{Ti - Ta} = 0.5$, where Tp is the temperature measured in the product during cooling, Ti is the initial temperature of the fruit, and Ta is the temperature in the cooling medium (water at 1ºC). However, in other pre-cooling treatments (Field cooling and Air Cooling) the fruit pulp temperature was estimated at regular interval till the temperature become constant (Mahajan *et al.,* 2023).

3.1.1.1.2. Pre-cooling Treatments

The selected fruits were subjected to three methods of pre-cooling viz., Hydro-cooling, Air cooling and Field cooling (Plate 2). In Hydro-cooling method, the fruits were immersed in the cold water at temperature 1° C. The water was treated with an active chlorine solution (150 mg/l) (Teruel *et al*., 2004). Water temperature was continuously maintained by adding crushed ice when necessary and checked by use of thermometer thermocouples. A volume ratio of 3:1:1 of water, ice and fruit weight, respectively was used as recommended by the USDA for hydro-cooling (Hardenburg *et al.,* 1990; Kitinoja and Gorny, 1999). In Air cooling, apple fruits were exposed to cold air produced from the table fan. However, in field cooling immediately after harvesting, the fruits were kept under shade conditions.

3.1.1.1.3. Storage of Fruits

After hydro-cooling, the fruits were drained, separated in different CFB carton (10 kg) and fruits cooled by air cooling and field cooling, after attaining constant temperature the fruits were immediately stored for 28 days at room temperature (20-22° C) (Lu *et al.,* 2021). Further the fruit analysis for different physico-chemical parameters was done at 7 days intervals.

3.1.2. Experiment No II: Studies on the storability of exotic cultivars of apple under different storage conditions

- **Treatment I (Cultivars - C):**
  - C_1: Jeromine
  - C_2: Redlum Gala
- **Treatment II (Storage Temperature – T):**
  - T_1: 0˚ C
  - T_2: 4˚ C
  - T_3: Room Temperature (20-22˚ C)

- **Treatment III (Storage duration - D)**
  - D_1: 0 days
  - D_2: 15 days
  - D_3: 30 days
  - D_4: 45 days

Treatment Combinations (C x S x D = 24)

$C_1T_1D_1$	Jeromine + 0˚ C + 0 days
$C_1T_1D_2$	Jeromine + 0˚ C + 15 days
$C_1T_1D_3$	Jeromine + 0˚ C + 30 days
$C_1T_1D_4$	Jeromine + 0˚ C + 45 days
$C_1T_2D_1$	Jeromine + 4˚ C + 0 days
$C_1T_2D_2$	Jeromine + 4˚ C + 15 days
$C_1T_2D_3$	Jeromine + 4˚ C + 30 days
$C_1T_2D_4$	Jeromine + 4˚ C + 45 days
$C_1T_3D_1$	Jeromine +Room Temperature (20-22 °C) + 0 days
$C_1T_3D_2$	Jeromine +Room Temperature (20-22 °C) + 15 days
$C_1T_3D_3$	Jeromine +Room Temperature (20-22 °C) + 30 days
$C_1T_3D_4$	Jeromine +Room Temperature (20-22 °C) + 45 days
$C_2T_1D_1$	Redlum Gala + 0˚ C + 0 days
$C_2T_1D_2$	Redlum Gala + 0˚ C + 15 days
$C_2T_1D_3$	Redlum Gala + 0˚ C + 30 days
$C_2T_1D_4$	Redlum Gala + 0˚ C + 45 days
$C_2T_2D_1$	Redlum Gala + 4˚ C + 0 days
$C_2T_2D_2$	Redlum Gala + 4˚ C + 15 days
$C_2T_2D_3$	Redlum Gala + 4˚ C + 30 days
$C_2T_2D_4$	Redlum Gala + 4˚ C + 45 days
$C_2T_3D_1$	Redlum Gala +Room Temperature (20-22 °C) + 0 days
$C_2T_3D_2$	Redlum Gala +Room Temperature (20-22 °C) + 15 days
$C_2T_3D_3$	Redlum Gala +Room Temperature (20-22 °C) + 30 days
$C_2T_3D_4$	Redlum Gala +Room Temperature (20-22 °C) + 45 days

Treatment Combinations : 24

Replications : 3

Design : CRD (Factorial)

Hydro-cooling (Cold Ice + Chlorine solution)

Final fruit pulp temperature of Hydro-cooled fruits.

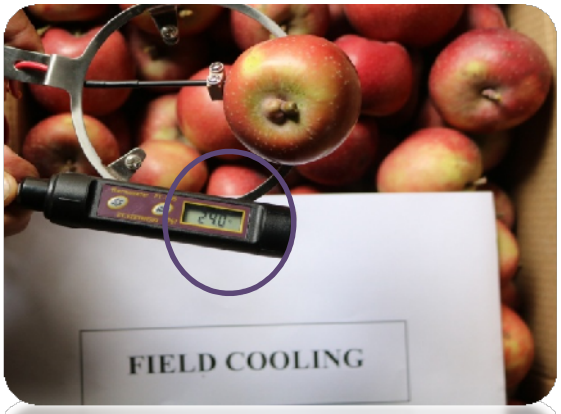
Plate 2 (a) Hydro-cooling

Air cooling

Final fruit pulp temperature of Air cooled fruits

Plate 2 (b) Air cooling

Field cooling



Final fruit pulp temperature of Field cooled fruits

Plate 2 (c) Field cooling

3.1.2.1. METHODOLOGY

Jeromine and Redlum Gala cultivar fruits of uniform size and weight were harvested after attaining maturity on 26/7/2022 and 21/7/2022, respectively, and were selected for conducting this experiment. After harvesting, the fruits were washed, surface dried and kept in trays of CFB and perforated bags in three replications which consists of 10 fruits per replication per cultivars.

3.1.2.1.1. Storage of Fruits

The selected fruits were stored at 0°C, 4°C and ambient room temperature (20-22 °C) for 45 days. For maintaining 0°C, the fruits were stored in cold store chamber of Department of Floriculture and Landscaping, UHF Nauni with RH of 90-95 %, and storage at 4° C was done in refrigerator of the Department of Fruit Science, UHF, Nauni, Solan (Plate 3). Further, at fifteen days intervals, the data on different physico-chemical parameters was observed.

3.2. OBSERVATION RECORDED

3.2.1. Fruit weight (g)

The weight of randomly selected twenty fruits was measured with the help of digital weighing balance and average fruit weight was expressed as gram per fruit.

3.2.2. Fruit volume (cc)

Fruit volume was computed using the water displacement method. Fruits which were taken for recording fruit weight were submerged in known volume of water filled in measuring beaker to obtain certain graduation. The difference between initial and final readings gave the measurement of fruit volume which was expressed in cubic centimetres (cc).

3.2.3. Fruit density (g/cc)

Fruit density was calculated by dividing the fruit weight to the fruit volume.

$$\text{Fruit Density} = \frac{\text{Fruit Weight (g)}}{\text{Fruit Volume (cc)}}$$

3.2.4. Physiological Loss in Weight (% -PLW)

Pre-weighed fruit samples were weighed on a physical balance after each storage interval. The loss in weight at each interval during storage was expressed as per cent of initial weight.

$$\text{Physiological Loss in Weight (PLW)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

3.2.5. Fruit firmness (kg/cm^2)

Fruit firmness was determined by using ACUCAL Digital Fruit Pressure Tester. The fruit skin was removed in circular thin slice of about 1 cm diameter with the help of a stainless-steel knife. The penetrometer was adjusted to zero and finally pierced into the fruit up to the knob and the value (fruit pressure) was expressed in kg/cm^2 as fruit firmness.

3.2.6. Total Soluble Solids (ºB)

Total soluble solids content was measured with the help of Milwaukee MA-871 digital refractometer (0-85˚B). Before use, the refractometer was calibrated with distilled water. A temperature correction was applied when the temperature is above and below 20^{o}C (AOAC, 1980). Few drops of fruit juice were dropped on the prism to record readings. The values of total soluble solids of such fruits were averaged and expressed as ˚B.

3.2.7. Titratable acidity (%)

The titratable acidity was determined by standard method (Ranganna, 1995). Twenty five grams of fresh fruit pulp (prepared using mixer grinder) from the fruit sample was taken, mixed thoroughly with distilled water by shaking the volumetric flask manually and final volume was made to 250 ml. Whatman No. 1 filter paper was then used to filter the mixture. After filtration the mixture, 25 ml of extract was taken into a conical flask and then titrated against 0.1 N NaOH solution using 2-3 drops of phenolphthalein as an indicator till it gave pink colour as the end point. The remaining filtered solution was used for estimation of sugars. Titratable acidity was expressed in terms of percentage (%) and was calculated by using the formula as under:

$$\text{Titratable acidity (\%)} = \frac{\text{Titre value} \times \text{Normality of NaOH} \times \text{Eq. wt. of acid} \times \text{Volume made up}}{\text{Weight of sample} \times \text{aliquot taken} \times 1000} \times 100$$

Equivalent weight (Eq. wt.) of malic acid = 67.05.

Fruit Stored at 0°C

Fruit Stored at 4°C

Fruit Stored at Room Temperature (20-22°C)

Plate 3 Fruit stored at different storage temperatures

3.2.8. Total sugars (%)

The sugar content of the fruit was determined by volumetric method based on the principle that sucrose content of fruit is quantitatively hydrolyzed to glucose and fructose in the presence of hydrochloric acid (HCl) as per the method suggested by Ranganna (1995).

The remaining filtered solution left from the titratable acidity was taken into a 250 ml volumetric flask and 5 ml of 45 per cent standard lead acetate was added to it. After about 10 minutes, 5 ml of 22 per cent potassium oxalate was added to precipitate excess of lead acetate and volume was made to 250 ml with distilled water. The solution was then filtered with Whatman No.1 filter paper. From filtered solution, 50 ml of filtrate was taken into separate volumetric flask and hydrolysed by adding 5 ml concentrated HCl. The solution was left overnight at room temperature for hydrolysis of sugars present in the solution. On the next day, excess of HCl was neutralized with standard 1N NaOH solution and final volume was made to 250 ml with distilled water. Here, the total sugars was estimated by titrating boiling mixture of 5 ml each of Fehling A and Fehling B against hydrolyzed filtrate solution using methylene blue as an indicator. Appearance of brick red colour indicated the end point. The total sugars were expressed as percentage (%) of fresh weight of the fruit pulp.

$$\text{Total sugars (\%)} = \frac{\text{Factor} \times \text{Dilution 1} \times \text{Dilution 2}}{\text{Titre value} \times \text{Weight of sample} \times \text{Volume of aliquot}} \times 100$$

Where, Factor = 0.05

3.2.9. Reducing sugars (%)

The remaining unhydrolysed, deleaded and clarified solution from total sugars estimation was titrated against the boiling mixture of 5 ml each of Fehling A and Fehling B using methylene blue as an indicator to determine the reducing sugars. It was expressed in percentage (%) of fresh fruit pulp weight basis (Ranganna, 1995).

$$\text{Reducing sugars (\%)} = \frac{\text{Factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight of sample taken}} \times 100$$

Where, Factor = 0.05

3.2.10. Non-reducing sugars (%)

The amount of non-reducing sugars was calculated by subtracting the amount of reducing sugars from total sugars and multiplying the difference by a standard factor whose value is 0.95. It was expressed in percentage (%).

$$\text{Non} - \text{reducing sugars (\%)} = (\text{Total sugars} - \text{reducing sugars}) \times 0.95$$

3.2.11. Ascorbic acid (mg/100g)

Ascorbic acid of the fruit sample was determined as per A.O.A.C. (1980) methods using following reagents and procedure as under:

(A) Reagents

a. Extraction solution

Three per cent of metaphosphoric acid was prepared by dissolving 15 grams of its pallets in 40 ml of glacial acetic acid and 200 ml of distilled water. The final volume was made to 500 ml with distilled water. The solution was filtered rapidly through filter paper and stored in refrigerator.

b. Ascorbic acid standard

Hundred milligrams of analytical grade L-ascorbic acid was precisely weighed on the electronic top pan balance and dissolved in small quantity of extraction solution. The final volume was made up to 100 ml with extraction solution in volumetric flask. Out of the stock solution made, 10 ml of the solution was taken and diluted again with 3 per cent metaphosphoric acid to obtain the working solution of L- ascorbic acid.

c. Indophenols standard dye solution

The dye was prepared by dissolving 50 mg sodium salt of 2, 6-dichlorophenol indophenols in about 150 ml hot distilled water containing 42 mg of sodium bicarbonate. It was shaken vigorously until the dye had dissolved and diluted to 200 ml with distilled water. The dye solution was stored into an amber stopper bottle and stored in refrigerator.

d. Standardization of the dye

Five ml of working solution of L-ascorbic acid and 5 ml of extraction solution were taken in the flask and titrated against the dye solution until the solution became pink in colour, which persisted for 10-15 seconds. The dye factor was determined by calculating milligrams of ascorbic acid reacting to 1 ml of the dye, using formula as under:

$$\text{Dye factor} = \frac{0.5}{\text{Titre}}$$

(B) Procedure for estimation of ascorbic acid in fruit sample

Five grams of fruit pulp was homogenized in 10-15 ml extraction solution and final volume was made to 50 ml in volumetric flask with extraction solution. Five ml of clarified extract was titrated against indophenols dye. The appearance of light rose pink colour indicated the end point, which persisted for 10-15 seconds. The titre reading was noted and the content of ascorbic acid in mg/100 g of fresh fruit pulp weight was calculated by using the following formula:

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Dye factor} \times \text{Titre value} \times \text{Volume made}}{\text{Weight of the fruit taken} \times \text{Volume of aliquot}} \times 100$$

3.2.12. Anthocyanin content (OD)

Anthocyanin content in apple skin was determined by the method described by Harborne (1973). One gram of apple fruit skin was macerated in a known quantity of methanol containing 1 per cent hydrochloric acid. The mixture was kept overnight at 0 °C temperature in a deep freezer. The absorbance of red coloured solution was recorded at 530 nm on Spectrophotometer (NUKES). Anthocyanin content was expressed as absorption units (OD – Optical Density) at 530 nm per gram fresh apple fruit skin.

3.2.13. Total phenols (mg GAE/100g)

The total phenols in apple (fruit sample) were estimated by Folin-Ciocalteau reagent method as described by Singleton and Rossi (1965). One gram of fruit sample was weighed and crushed in 10 ml of 80 per cent ethanol. The crushed mixture was centrifuged at 10,000 rpm for 20 minutes at 4^{o}C temperature in refrigerated centrifuge and the supernatant was collected. From the supernatant, 100 µl (0.1 ml) aliquot was taken in a test tube and 0.5 ml of 2 N Folin-Ciocalteau reagent + 2.9 ml of distilled water were added. After 3 minutes, 2 ml of 20 per cent Na_2CO_3 was added. The sample was thoroughly mixed and was allowed to stand for some time till highly dark blue coloured complex (molybdenum blue) appeared. A blank sample was prepared in a similar manner by taking 3 ml distilled water instead of the fruit sample. The intensity of colour was measured at 760 nm in Spectrophotometer (NUKES). The concentration was determined as per the standard procedure from the standard curve. A standard calibration curve of gallic acid using its different concentrations was prepared.

Absorbance was then plotted against concentration and concentration of total phenols in the sample was calculated and expressed as mg GAE/100 g of sample.

3.2.14. Antioxidant activity (%)

3.2.14.1 DPPH (2,2-Diphenyl-1-picrylhydrazyl) radical scavenging activity

Free radical scavenging activity was measured as per the method of Williams *et al*. (1995). DPPH was used as a source of free radical. A quantity of 3.9 ml of $6x10^{-5}$ mol/L DPPH in methanol was taken in a cuvette with 0.1 ml of methanolic extract of sample (1ml/g sample in 3 ml methanol) and the decrease in absorbance was measured at 515 nm after 30 minutes. Methanol was used as blank and anti-oxidant activity was calculated by using the following formula:

$$\text{Antioxidant activity (\%)} = \frac{\text{Absorbance of DPPH} - \text{Absorbance of sample}}{\text{Absorbance of DPPH}} \times 100$$

3.2.15. Sensory Evaluation (9- Point Hedonic Scale)

During each interval of the storage period, five apples were subjected to sensory evaluation by the panel of 5 judges including male and female in the age group of 20-60 years (Torri *et al*., 2012) from the Department of Fruit Science and Department of Food Science and Technology, UHF Nauni Solan (HP), India. Sensory evaluation was done according to the procedure and guidelines recommended by Ranganna (1995) by Hedonic rating test and as per the method recommended by Indian Standard (BIS IS: 6273-2: Guide for Sensory Evaluation of Foods, Part II: Methods and Evaluation Cards). The evaluation was done on the basis of colour, texture, flavor, taste, juiceness and lastly overall acceptability on the basis of 9 points Hedonic scale (9 – Like Extremely; 8 - Like Very Much; 7 - Like Moderately; 6 - Like Slightly; 5 - Neither Like not Dislike; 4 - Dislike Slightly; 3 – Dislike Moderately; 2 – Dislike Very Much; 1 – Dislike Extremely). Responses to all the panelists were recorded in the format of sensory evaluation (Appendix I).

3.3 STATISTICAL ANALYSIS

3.3.1. Experiment 1

The data obtained from this investigation were appropriately computed, tabulated and analysed by using MS-Excel and OPSTAT. The data was analyzed according to the procedure for analysis of Completely Randomized Design (factorial) for laboratory

experiment and the significance of each data will be calculated as suggested by Panse and Sukhatme (2000).

Experimental Design: Completely Randomized Block Design (CRD) factorial

No. of treatments combinations	:	20
No. of precooling methods	:	04
No. of cultivar	:	01
No. of time of storage days	:	05
No. of replications	:	03

ANOVA for CRD Factorial

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	$F_{(cal)}$
Treatment combinations (t)	(t-1)	S_t	$M_t = \frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Precooling methods (p)	(p-1)	S_p	$M_p = \frac{S_p}{(p-1)}$	$\frac{M_p}{M_e}$
Storage days (d)	(d-1)	S_d	$M_d = \frac{S_d}{(d-1)}$	$\frac{M_d}{M_e}$
Precooling methods (p)× Storage days (d) interaction	(p-1) (d-1)	S_{pd}	$M_{pd} = \frac{S_{pd}}{(p-1)(d-1)}$	$\frac{M_{pd}}{M_e}$
Error	t(r-1)	S_e	$M_e = \frac{S_e}{(t(r-1))}$	
Total	rt-1	S_T		

Where,

t	=	Number of treatments
r	=	Number of replications
p	=	Precooling methods
d	=	Storage days
S_t	=	Sum of square due to treatments
S_p	=	Sum of square due to precooling methods
S_d	=	Sum of square due to storage days
S_{pd}	=	Sum of square due to interaction between precooling methods and storage days
S_e	=	Sum of squares due to error
S_T	=	Total sum of squares

M_t = Mean sum of square due to treatments

M_p = Mean sum of square due to precooling methods

M_d = Mean sum of square due to storage days

M_{pd} = Mean sum of square due to interaction between precooling methods and storage days

M_e = Mean sum of square due to error

The replication and treatment mean sum of square were tested against mean sum of squares due to error by 'F' test at (t-1), t(r-1) degree of freedom at 5% level of significance. The calculated F-values were compared with tabulated F- value. If the calculated value was higher than the tabulated one, it was considered to be significant.

If the treatments were significantly different, the comparison of the treatments were carried out on the basis of critical difference (CD).

The standard error of mean SE (m) and critical difference (CD) for comparing the means of any two treatments were calculated as below:

SE (m) = $\pm \sqrt{\frac{M_e}{r}}$

SE (d) = $\pm \sqrt{\frac{2M_e}{r}}$

$CD_{0.05}$ = $t_{(0.05,\ t(r-1)\ df)} \times SE(d)$

SE (m) = Standard error of mean

SE (d) = Standard error of differences of means

$CD_{0.05}$ = Critical difference at 5 per cent level of significance.

3.3.2. Experiment 2

The data obtained from this investigation were appropriately computed, tabulated and analyzed by using MS-Excel and OPSTAT. The data was analyzed according to the procedure for analysis of Completely Randomized Design (factorial) for laboratory experiment and the significance of each data will be calculated as suggested by Panse and Sukhatme (2000).

Experimental Design: Completely Randomized Block Design (CRD) Factorial

No. of treatments combinations : 24

No. of cultivars : 02

No. of storage temperature : 03

No. of time of storage duration : 04

No. of replications : 03

ANOVA for Factorial CRD

Source of variation (SV)	Degree of freedom (df)	Sum of squares (SS)	Mean sum of squares (MSS)	F-Cal. Value
Treatment combinations (T)	T - 1	S_T	$M_T = \frac{S_T}{(T-1)}$	$\frac{M_T}{M_e}$
Cultivars (c)	c - 1	S_c	$M_c = \frac{S_c}{(c-1)}$	$\frac{M_c}{M_e}$
Storage temperature (t)	t - 1	S_t	$M_t = \frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Storage duration (d)	d - 1	S_d	$M_d = \frac{S_d}{(d-1)}$	$\frac{M_d}{M_e}$
Cultivars × Storage temperature (c × t)	(c – 1) (t - 1)	S_{ct}	$M_{ct} = \frac{S_{ct}}{(c-1)(t-1)}$	$\frac{M_{ct}}{M_e}$
Cultivars × Storage duration (c × d)	(c - 1) (d - 1)	S_{cd}	$M_{cd} = \frac{S_{cd}}{(c-1)(d-1)}$	$\frac{M_{cd}}{M_e}$
Storage temperature × Storage duration (t × d)	(t – 1) (d – 1)	S_{td}	$M_{td} = \frac{S_{td}}{(t-1)(d-1)}$	$\frac{M_{td}}{M_e}$
Cultivars ×Storage temperature ×Storage duration (c × t × d)	(c – 1) (t - 1) (d - 1)	S_{ctd}	$M_{ctd} = \frac{S_{ctd}}{(c-1)(t-1)(d-1)}$	$\frac{M_{ctd}}{M_e}$
Error	T (r - 1)	S_e	$M_e = \frac{S_e}{T(r-1)}$	
Total	r T - 1	S_T,		

Where,

T = Number of treatments

r = Number of replications

c = No. of cultivars

t = Storage temperature

d = Storage days

S_t = Sum of square due to treatments

S_c = Sum of square due to no. of cultivars

S_t = Sum of square due to storage temperature

S_d = Sum of square due to storage duration

S_{ct} = Sum of square due to interaction between No. of cultivars and storage temperature

S_{cd} = Sum of square due to interaction between No. of cultivars and storage

duration

S_{td} = Sum of square due to interaction between storage temperature and storage duration

S_{ctd} = Sum of square due to interaction between no. of cultivars, storage temperature and storage duration

S_e = Sum of squares due to error

$S_{T'}$ = Total sum of squares

M_T = Mean sum of square due to treatments

M_c = Mean sum of square due to no. of cultivars

M_t = Mean sum of square due to storage temperature

M_d = Mean sum of square due to storage duration

M_{ct} = Mean sum of square due to interaction between no. of cultivars and storage temperature

M_{cd} = Mean sum of square due to interaction between no. of cultivars and storage duration

M_{td} = Mean sum of square due to interaction between no. of storage temperature and storage duration

M_{ctd} = Mean sum of square due to interaction between no. of cultivars, storage temperature and storage duration

M_e = Mean sum of square due to error

The replication and treatment mean sum of square were tested against mean sum of squares due to error by 'F' test at (t-1), t(r-1) degree of freedom at 5% level of significance. The calculated F-values were compared with tabulated F- value. If the calculated value was higher than the tabulated one, it was considered to be significant.

If the treatments were significantly different, the comparison of the treatments were carried out on the basis of critical difference (CD).

The standard error of mean SE (m) and critical difference (CD) for comparing the means of any two treatments were calculated as below:

$$\text{SE (m)} = \pm \sqrt{\frac{M_e}{r}}$$

SE (d) = $\pm \sqrt{\frac{2M_e}{r}}$

$CD_{0.05}$ = $t_{(0.05,\, t\,(r-1)\ df)} \times SE(d)$

SE (m) = Standard error of mean

SE (d) = Standard error of differences of means

$CD_{0.05}$ = Critical difference at 5 per cent level of significance

Chapter-4

RESULTS AND DISCUSSION

The present study entitled **"Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"** was conducted in the Department of Fruit Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the year 2022. The experimental results obtained during the course of study are presented and discussed in this chapter under the following heads:

4.1 EXPERIMENT NO. I: - Effect of different precooling methods on the storability of apple cv. Jeromine

4.1.1 Fruit weight

The data related to fruit weight as influenced by different precooling treatments and storage days are presented in Table 4.1. It is clearly evident from the persual of data presented in Table 4.1 that the different precooling treatments and storage days exhibited a significant effect on fruit weight of apple cultivar Jeromine. The highest fruit weight (107.35 g) was recorded in treatment P_3 (Hydro-cooling) which was statistically at par with P_4 (Air-Cooling). However, the lowest fruit weight (100.69 g) was observed in treatment P_1 (Control) which was significantly lower than all other pre-cooling treatments.

With respect to storage days, the fruit weight showed decreasing trend with increasing storage days. The maximum fruit weight (131.56 g) was observed in fruit stored for 0 days (D_1), which was significantly followed by the fruits stored for 7 days (D_2) and 14 days (D_3). The minimum fruit weight (80.08 g) was observed in fruits stored for 28 days (D_5) which was significantly lower than all other storage days.

The interaction effect between precooling treatments and storage days was found significant. Although, the highest fruit weight (131.92 g) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days), which was statistically at par with treatment combinations P_1 D_1 (Control + 0 days), P_2 D_1 (Field Cooling + 0 days) and P_4 D_1 (Air Cooling + 0 days). Under all the precooling treatments fruit weight decreased significantly with the increase in storage days. The fruit weight decreased from 130.86, 131.67, 131.92 and 131.79 g to 71.95, 81.33, 84.61 and 82.44 g in control, field-cooling, hydro-cooling and air-cooling

respectively, during storage for 28 days. However, after 28 days of storage the highest fruit weight (84.61 g) was recorded in P_3 D_5 (Hydro-cooling + 28 days) which was statistically at par with P_2 D_5 (Field Cooling + 28 days) and P_4 D_5 (Air-Cooling + 28 days), whereas, the lowest fruit weight (71.95 g) was recorded in P_1 D_5 (Control + 28 days).

4.1.2 Physiological loss in weight

It is clearly evident from the data presented in Table 4.1 that the different precooling treatments and storage days exhibited a significant effect on physiological loss in weight of apple cultivar Jeromine. The highest physiological loss in weight (23.04 %) was recorded in treatment P_1 (Control), which was statistically at par with P_2 (Field cooling). However, the lowest physiological loss in weight (18.61 %) was recorded in P_3 (Hydro-cooling) which was statistically at par with treatment P_4 (Air-Cooling).

With respect to storage, the physiological loss in weight showed increasing trend with increase in storage days. The highest physiological loss in weight (39.13 %) was recorded in fruit stored for 28 days (D_5) as compared to lowest in fruit stored for 0 day ($D_{1)}$.

The interaction between different precooling treatments and storage days exhibited a significant effect on physiological loss in weight. However, the physiological loss in weight increases with increasing storage time with respect to different precooling treatments. Although, the fruits stored for 0 days in all precooling treatments resulted zero physiological loss in weight percentage. However, with further increase in storage days, the treatment combination P_3 D_2 (Hydro-cooling + 7 days) recorded lowest physiological loss in weight (9.26 %) which was statistically at par with P_1 D_2 (Control + 7 days), P_2 D_2 (Field cooling + 7 days) and P_4 D_2 (Air-cooling + 7 days). Again, with further storage for 14 days, 21 days and 28 days, the treatment combination P_3 D_3 (Hydro-cooling + 14 days), P_3 D_4 (Hydro-Cooling + 21 days) and P_3 D_5 (Hydro-Cooling + 28 days) recorded lowest physiological loss in weight (18.85 per cent, 29.05 per cent and 35.86 per cent respectively) in comparison to all other treatment combinations of precooling and storage days (Figure 1). However, the highest physiological loss in weight (45.00 %) was recorded in treatment combination P_1 D_5 (Control + 28 days) which was significantly higher than all other treatment combinations.

The results from the present experiment depicted that the fruit weight showed a decreasing trend with increasing storage duration and further resulted in increase in physiological loss in weight (Table 4.1).

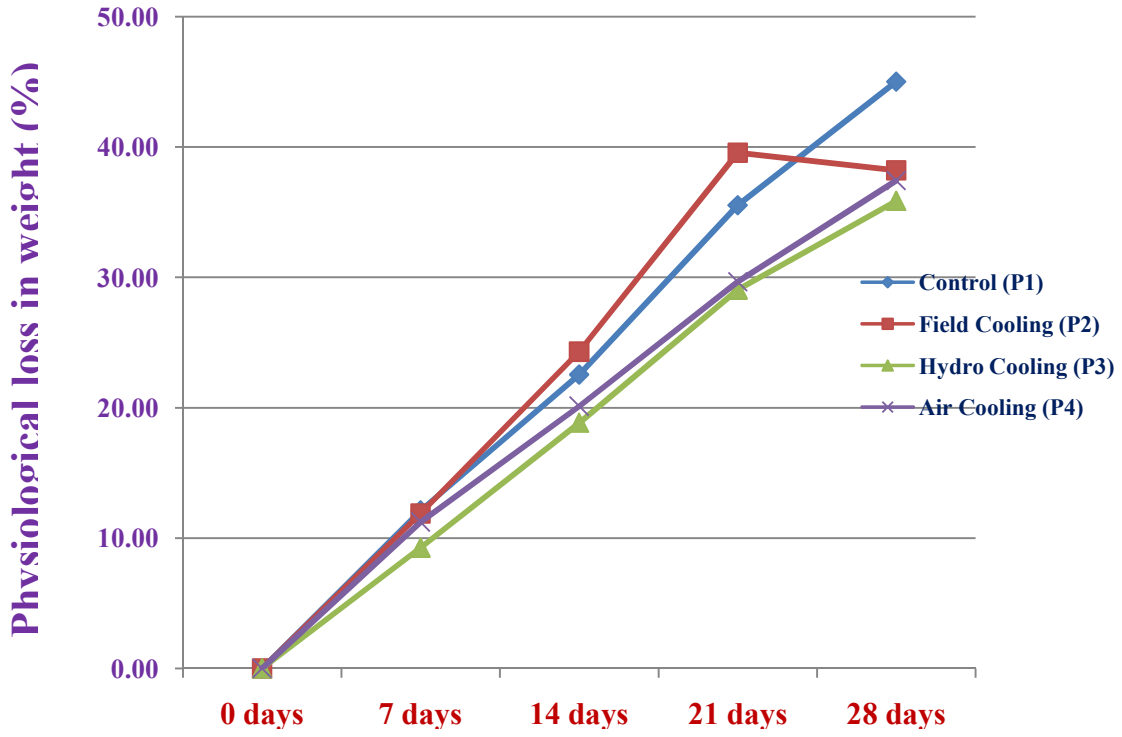


Figure 1. Effect of different precooling treatments and storage time on physiological loss in weight of apple cv. Jeromine

Table 4.1 Effect of different precooling treatments and storage duration on fruit weight and physiological loss in weight of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Fruit Weight (g)						Physiological loss in weight (%- PLW)					
	D_1 (0 days)	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**	**D_1 (0 days)**	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**
P_1 (Control)	130.86	115.00	101.33	84.33	71.95	**100.69**	0 (0.00)	12.11 (20.34)*	22.54 (28.31)	35.53 (36.57)	45.00 (42.11)	**23.04 (25.47)**
P_2 (Field Cooling)	131.67	116.00	103.50	90.67	81.33	**104.63**	0 (0.00)	11.89 (20.14)	24.30 (29.51)	39.56 (38.95)	38.21 (38.16)	**22.79 (25.35)**
P_3 (Hydro-Cooling)	131.92	119.67	107.00	93.59	84.61	**107.35**	0 (0.00)	9.26 (17.63)	18.85 (25.67)	29.05 (32.59)	35.86 (36.77)	**18.61 (22.54)**
P_4 (Air Cooling)	131.79	117.00	105.28	92.67	82.44	**105.83**	0 (0.00)	11.23 (19.56)	20.12 (26.64)	29.67 (32.97)	37.42 (37.69)	**19.69 (23.37)**
Mean (D)	**131.56**	**116.92**	**104.28**	**90.32**	**80.08**		**0 (0.00)**	**11.13 (19.42)**	**21.46 (27.54)**	**33.45 (35.27)**	**39.13 (38.68)**	
	$CD_{0.05}$ P – 1.65 D – 1.84 P × D – 3.69						$CD_{0.05}$ P – 1.36 D – 1.53 P × D – 3.05					

*Data in parenthesis are angularly transformed values.

However, the pre-cooling treatment variably showed significant effect on both fruit weight and physiological loss in weight. Fruits precooled with hydro-cooling and air-cooling exhibited lesser proportion of physiological loss in weight in apple fruits during storage. This might be due to reduction in rate of respiration, water loss, as well as delay in ripening process caused by precooling effect. The present result are in confirmatory with those of Patel (2006), who also reported that the lesser physiological loss in weight of mango by precooling treatment during storage. The present results are also in line with those of Matouk *et al*. (2018) who also reported lower moisture loss in apple fruits precooled with hydro-cooling treatment in comparison to non-precooled fruits. Sena *et al*. (2019) also recorded lower physiological fruit weight loss in cashew apples when precooled with hydro-cooling.

4.1.3 Fruit volume

The persual of data presented in Table 4.2 indicated that the different precooling treatments and storage days exhibited a significant effect on fruit volume of apple under storage. The highest fruit volume (121.80 cc) was recorded in treatment P_3 (Hydro-cooling) which was significantly higher than all other precooling treatments. However, the lowest fruit volume (114.07 cc) was observed in control (P_1).

The fruit volume showed decreasing trend with respect to increase in storage days. The maximum fruit volume (144.17 cc) was observed in fruit stored for 0 days (D_1), which was significantly followed by fruits stored for 7 days (D_2). The minimum fruit volume (93.33 cc) was observed in fruits stored for 28 days (D_5).

The interaction between precooling treatments and storage days had a significant effect on fruit volume. The highest fruit volume (146.33 cc) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days), which was statistically at par with treatment combinations P_1 D_1 (Control + 0 days), P_2 D_1 (Field cooling + 0 days) and P_4 D_1 (Air-Cooling + 0 days). However, with respect to further increase in storage time and different precooling treatments, the fruit volume varied significantly. During 28 days of storage, the highest fruit volume was observed in treatment combination P_3 D_2 (Hydro cooling + 7 days), P_3 D_3 (Hydro cooling + 14 days), P_3 D_4 (Hydro-cooling + 21 days) and P_3 D_5 (Hydro cooling + 28 days) recording fruit volume of 132.00 cc, 122.00 cc, 110.00 cc and 98.67 cc respectively in comparison to all other treatment combinations of storage time and precooling treatments. The lowest fruit volume (83.00 cc) was observed in treatment combination P_1D_5 (Control + 28 days).

Table 4.2 Effect of different precooling treatments and storage duration on fruit volume and fruit density of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Fruit Volume (cc)						Fruit Density (g/cc)					
	D_1 (0 days)	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**	**D_1 (0 days)**	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**
P_1 (Control)	142.67	130.00	113.67	101.00	83.00	**114.07**	0.920	0.883	0.893	0.833	0.867	**0.879**
P_2 (Field Cooling)	143.66	130.33	116.67	102.67	94.00	**117.47**	0.917	0.887	0.887	0.883	0.867	**0.888**
P_3 (Hydro-Cooling)	146.33	132.00	122.00	110.00	98.67	**121.80**	0.903	0.907	0.880	0.853	0.857	**0.880**
P_4 (Air Cooling)	144.00	131.33	119.00	103.00	97.67	**119.00**	0.913	0.893	0.883	0.897	0.843	**0.886**
Mean (D)	**144.17**	**130.92**	**117.83**	**104.17**	**93.33**		**0.913**	**0.893**	**0.886**	**0.867**	**0.858**	
	$CD_{0.05}$ P – 2.31 D – 2.58 P × D – 5.16						$CD_{0.05}$ P – NS D – 0.015 P × D – 0.029					

4.1.4 Fruit Density

The data presented in Table 4.2 depicted that the different precooling treatments exhibited a non-significant effect on fruit density, whereas, storage days had a significant effect on fruit density. However, the highest fruit density (0.888 g/cc) was recorded in treatment P_2 (Field cooling) and the lowest fruit density (0.879 g/cc) was observed in treatments control (P_1).

Regarding different storage duration, the maximum fruit density (0.913 g/cc) was observed in fruit stored in 0 days (D_1). The minimum fruit density (0.858 g/cc) was observed in fruits stored for 28 days (D_5), which was statistically at par with fruits stored for 21 days (D_4).

The interaction between precooling treatments and storage days had significant effect on fruit density. The highest fruit density (0.920 g/cc) was recorded in treatment combination P_1 D_1 (Control + 0 days) which was statistically at par with P_2 D_1 (Field cooling + 0 days), P_3 D_1 (Hydro-cooling + 0 days) and P_4 D_1 (Air-Cooling + 0 days). However, with respect to further increase in storage time and pre-cooling treatments, the highest fruit density (0.907 g/cc) was observed in treatment combination P_3 D_2 (Hydro-cooling + 7 days), which was statistically at par with treatment combinations P_3 D_3 (Hydro-cooling + 14 days), P_1 D_2 (Control + 7 days), P_2 D_2 (Field cooling + 7 days) and P_4 D_2 (Air-cooling + 7 days). The lowest fruit density (0.833 g/cc) was recorded in P_1 D_4 (Control + 21 days), which was statistically at par with treatment combinations P_4 D_5 (Air-cooling + 28 days), P_3 D_4 (Hydro-cooling + 21 days) and P_3 D_5 (Hydro-cooling + 28 days).

4.1.5 Fruit Firmness

The perusal of data presented in Table 4.3 indicated that the different precooling treatments and storage days exhibited a significant effect on fruit firmness during storage. The highest fruit firmness (4.60 kg/cm^2) was recorded in treatment P_3 (Hydro-cooling) which was significantly higher than all other precooling treatments. However, the lowest fruit firmness (4.18 kg/cm^2) was observed in control (P_1).

With respect to storage days, the fruit firmness showed decreasing trend with increasing storage time irrespective of precooling treatments. The maximum fruit firmness (8.66 kg/cm^2) was observed in fruit stored in 0 days (D_1), which was significantly higher than

all the storage days. However, among further storage days, the fruits stored for 7 days (D_2) recorded highest fruit firmness (5.31 kg/cm^2) than fruits stored for 14 days, 21 days and 28 days. The minimum fruit firmness (2.18 kg/cm^2) was observed in fruits stored for 28 days (D_5).

The interaction between precooling treatments and storage days was found significant. The highest fruit firmness (8.78 kg/cm^2) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days), which was statistically at par with P_2 D_1 (Field cooling + 0 days) and P_4 D_1 (Air-Cooling + 0 days). However, after further storage, the highest fruit firmness (5.50 kg/cm^2) was observed in treatment combination P_3 D_2 (Hydro-cooling + 7 days) which was significantly followed by treatment combination P_4 D_2 (Air-Cooling + 7 days). However, after 28 days of storage, the highest fruit firmness (2.35 kg/cm^2) was recorded in P_3D_5 (Hydro-cooling + 28 days) which was statistically at par with P_4 D_5 (Air-Cooling + 28 days) and the lowest fruit firmness (1.87 kg/cm^2) was recorded in P_1 D_5 (Control + 28 days).

The fruit firmness showed decreasing trend with respect to increase in storage time might be due to increase in activity of various cell wall dissolving enzymes leading to gradual degradation of cell wall. The pre-cooling treatment especially hydro-cooling resulted lesser rate of decrease in fruit firmness in comparison to other pre-cooling treatments with respect to increase in storage time. Hydro-cooling immediately after harvesting might had slowed down the enzymatic activities and maintained better firmness in comparison to other treatments. The results are in accordance with those of Matouk *et al*. (2018) who also observed higher fruit firmness under hydro-cooled apple fruits when compared with non-precooled fruits. Similar results were also obtained by Makwana *et al*. (2014) in mango fruit, where higher fruit firmness was attained in pre-cooled fruits. Mahajan *et al*. (2023) also recorded higher fruit firmness after 20 days of storage in pear fruits which were pre-cooled after harvest in comparison to fruits not subjected to pre-cooling.

4.1.6 Total soluble solids

The data depicted in Table 4.3 revealed, that the different precooling treatments and storage days exhibited a significant effect on total soluble solids content of apple. The maximum TSS content (11.48 °B) was recorded in treatment P_3 (Hydro-cooling) which was statistically at par with treatment P_4 (Air-Cooling). However, the minimum TSS content (11.27 °B) was observed in control (P_1).

Table 4.3 Effect of different precooling treatments and storage duration on fruit TSS and firmness of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Firmness (kg/cm^2)						TSS (°B)					
	D_1 (0 days)	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**	**D_1 (0 days)**	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**
P_1 (Control)	8.43	5.13	3.13	2.33	1.87	**4.18**	9.83	10.80	11.90	12.75	11.05	**11.27**
P_2 (Field Cooling)	8.69	5.27	3.27	2.60	2.22	**4.41**	9.67	10.43	11.87	12.66	12.33	**11.39**
P_3 (Hydro-Cooling)	8.78	5.50	3.53	2.85	2.35	**4.60**	9.43	10.23	11.67	12.51	13.54	**11.48**
P_4 (Air Cooling)	8.72	5.33	3.30	2.58	2.28	**4.44**	9.53	10.37	11.73	12.59	12.93	**11.43**
Mean (D)	**8.66**	**5.31**	**3.31**	**2.59**	**2.18**		**9.62**	**10.46**	**11.79**	**12.63**	**12.47**	
	$CD_{0.05}$	P – 0.04 D – 0.04 P × D – 0.09					$CD_{0.05}$	P – 0.06 D – 0.07 P × D – 0.13				

With respect to storage days, the fruit total soluble solids content increases up to an extent of storage and than further showed decreasing trend with increasing storage time. The maximum TSS content (12.63 °B) was observed in fruit stored for 21 days (D_4), which was significantly higher than all the storage days. The minimum TSS content (9.62 °B) was observed in fruits stored for 0 days (D_1).

The interaction between precooling treatments and storage days exerted a significant effect on total soluble solids content of fruits under storage. The maximum fruit TSS content (13.54 °B) was recorded in P_3 D_5 (Hydro-cooling + 28 days), which was significantly higher than all other treatment combinations. However, the minimum TSS content (9.43 °B) was recorded in P_3 D_1 (Hydro-cooling + 0 days) which was statistically at par with P_4 D_1 (Air-Cooling + 0 days).

4.1.7 Titratable Acidity

The data presented in Table 4.4 depicts that the different precooling treatments and storage days exhibited significant effect on titratable acidity. The highest titratable acidity (0.19 %) was recorded in treatment P_3 (Hydro-cooling), which was statistically at par with treatment P_4 (Air cooling). However, the lowest titratable acidity (0.16 %) was observed in control (P_1) which was statistically at par with treatment P_2 (Field cooling).

The titratable acidity decreases with respect to increasing storage time. The maximum titratable acidity (0.22 %) was observed in fruit stored in 0 days (D_1), which was significantly followed by fruits stored for 7 days (D_2). The minimum titratable acidity (0.15 %) was observed in fruits stored for 28 days (D_5) which was statistically at par with fruits stored for 21 days (D_4).

The interaction between precooling treatments and storage days exerted a non-significant effect on titratable acidity. However, the highest titratable acidity (0.24 %) was recorded in treatment combination P_3 D_1 (Hydro- cooling + 0 days) and the lowest titratable acidity (0.14 %) was recorded in P_1 D_5 (Control + 28 days).

4.1.8 Total Sugars

The data depicted in Table 4.4 indicated that the different precooling treatments and storage days exhibited a significant effect on total sugars content in apple under storage. The highest total sugars content (7.96 %) was recorded in treatment P_3 (Hydro-cooling). However, the lowest total sugars content (5.78 %) was observed in treatment P_1 (control).

Table 4.4 Effect of different precooling treatments and storage duration on fruit titratable acidity and total sugars content of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Titratable Acidity (%)						Total Sugars (%)					
	D_1 (0 days)	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**	**D_1 (0 days)**	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**
P_1 (Control)	0.19	0.17	0.16	0.16	0.14	**0.16**	6.53	6.19	5.87	5.35	4.96	**5.78**
P_2 (Field Cooling)	0.19	0.18	0.17	0.16	0.15	**0.17**	6.50	7.63	7.83	8.67	7.57	**7.64**
P_3 (Hydro-Cooling)	0.24	0.21	0.18	0.17	0.17	**0.19**	6.19	7.06	7.48	9.85	9.20	**7.96**
P_4 (Air Cooling)	0.22	0.19	0.17	0.17	0.16	**0.18**	6.28	7.17	7.57	9.20	8.57	**7.76**
Mean (D)	**0.22**	**0.18**	**0.17**	**0.16**	**0.15**		**6.38**	**7.01**	**7.19**	**8.27**	**7.58**	
	$CD_{0.05}$ P – 0.01 D – 0.01 P × D – NS						$CD_{0.05}$ P – 0.06 D – 0.07 P × D – 0.14					

With respect to storage duration, the fruit total sugars content increases up to an extent of storage and then further showed decreasing trend with increasing storage time. The maximum total sugars content (8.27 %) was observed in fruit stored for 21 days (D_4), which was significantly higher than all the storage days. However, the minimum total sugars content (6.38 %) was observed in fruits stored for 0 days (D_1).

The interaction between precooling treatments and storage days had significant effect on total sugars content. The highest total sugars content (9.85 %) was recorded in treatment combination P_3 D_4 (Hydro- cooling + 21 days). However, the lowest total sugars content (4.96 %) was recorded in P_1 D_5 (Control + 28 days).

4.1.9 Reducing Sugars

The perusal of the data depicted in Table 4.5 revealed that the different precooling treatments and storage days exhibited a significant effect on reducing sugars content. The highest reducing sugars content (4.37 %) was recorded in treatment P_3 (Hydro-cooling). However, the lowest reducing sugars content (3.03%) was observed in control (P_1).

With respect to storage days, the fruit reducing sugars content increases up to an extent of storage and then further showed decreasing trend with increasing storage time. The maximum reducing sugars content (4.28 %) was observed in fruit stored for 21 days (D_4), which was significantly higher than all the storage days. The minimum reducing sugars content (3.57 %) was observed in fruits stored for 0 days (D_1).

The interaction between precooling treatments and storage days exerted a significant effect on reducing sugars content. The highest reducing sugars content (5.11 %) was recorded in treatment combination P_3 D_4 (Hydro- cooling + 21 days) which was statistically at par with P_3 D_5 (Hydro- cooling + 28 days). The lowest reducing sugars content (2.26 %) was recorded in P_1 D_5 (Control + 28 days).

4.1.10 Non-Reducing Sugars

The data presented in Table 4.5 revealed that the different precooling treatments and storage days exhibited a significant effect on non-reducing sugars content. The highest non-reducing sugars content (3.41 %) was recorded in treatment P_3 (Hydro-cooling), which was

statistically at par P_4 (Air-cooling). However, the lowest non-reducing sugars content (2.62 %) was observed in treatment P_1 (Control).

The non-reducing sugars content showed increasing trend with increase in storage time up to an extent and then showed decreasing trend with increasing storage time. The maximum non-reducing sugars content (3.79 %) was observed in fruit stored for 21 days (D_4), which was significantly higher than all the storage days. The minimum non-reducing sugars content (2.67 %) was observed in fruits stored at 0 days (D_1).

The interaction between precooling treatments and storage days had a significant effect on non-reducing sugars content. However, the highest non-reducing sugars content (4.50 %) was recorded in treatment combination of P_3 D_4 (Hydro-cooling + 21 days), and the lowest non-reducing sugars content (2.38 %) was recorded in P_1 D_4 (Control + 21 days) which was statistically at par with P_1 D_1 (Control + 0 days).

The titratable acidity of the stored fruits declined with the prolonged storage period. However, the fruits pre-cooled with hydro-cooling and air-cooling recorded highest titratable acidity. This might be due to slower degradation of organic acid into sugars and decrease in rate of respiration under precooled fruits (Liang *et al*., 2013). The present findings are in line with those of Puttaraju and Reddy (1997) who also reported higher titratable acidity in pre-cooled mango fruits. Similarly, Jawandha *et al*. (2016) also recorded maximum titratable acidity in pre-cooled peach fruits in comparison to non-precooled fruits. The pre-cooled treated fruits exhibited a gradual increase in TSS and sugar content up to 21 days of storage and thereafter decreasing trend was noticed (Table 4.3, 4.4 and 4.5). Similar trend was also noticed in pear fruits when different pre-cooling treatments was employed and stored at ambient room temperature by Mahajan *et.al*. (2023). Among different pre-cooling treatments, hydro-cooling recorded highest TSS and sugars content, which might be due to more reduction of respiration rate and further slower down the conversion of starch into different proportion of sugars concentration, thus maintaining higher TSS and total sugars in fruits (Jawandha *et al*., 2016). The present results are also in line with those of Matouk *et al*. (2018), who also recorded highest total sugars content in hydro-cooled apple fruits in comparison to non-precooled apple fruits.

Table 4.5 Effect of different precooling treatments and storage duration on reducing and non-reducing sugars content of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Reducing Sugars (%)						Non-Reducing Sugars (%)					
	D_1 (0 days)	D_2 (7 days)	D_3 (14 days)	D_4 (21 days)	D_5 (28 days)	Mean (P)	D_1 (0 days)	D_2 (7 days)	D_3 (14 days)	D_4 (21 days)	D_5 (28 days)	Mean (P)
P_1 (Control)	3.69	3.27	3.05	2.85	2.26	**3.03**	2.70	2.77	2.68	2.38	2.56	**2.62**
P_2 (Field Cooling)	3.66	4.33	4.58	4.42	4.02	**4.20**	2.70	3.13	3.08	4.04	3.37	**3.27**
P_3 (Hydro-Cooling)	3.45	4.13	4.17	5.11	5.01	**4.37**	2.61	2.79	3.15	4.50	3.98	**3.41**
P_4 (Air Cooling)	3.48	4.22	4.36	4.74	4.50	**4.26**	2.66	2.80	3.05	4.24	3.87	**3.32**
Mean (D)	**3.57**	**3.99**	**4.04**	**4.28**	**3.95**		**2.67**	**2.87**	**2.99**	**3.79**	**3.45**	
	$CD_{0.05}$ P – 0.06 D – 0.06 P × D – 0.13						$CD_{0.05}$ P – 0.09 D – 0.10 P × D – 0.19					

4.1.11 Ascorbic acid

It is evident from the data depicted in Table 4.6 that the different precooling treatments and storage days exhibited a significant effect on ascorbic acid content. The highest ascorbic acid content (3.51 mg/100g) was recorded in treatment P_3 (Hydro-cooling), which was significantly higher than all other precooling treatments. However, the lowest ascorbic acid content (2.47 mg/100g) was observed in control (P_1).

With respect to storage days, the maximum ascorbic acid (4.44 mg/100g) was observed in fruit stored in 0 days (D_1), which further decreased with increasing storage time. After increase in storage period, the maximum ascorbic acid content (3.37 mg/100g) was observed in fruits stored for 7 days and the minimum ascorbic acid content (1.80 mg/100g) was observed in fruits stored for 28 days (D_5).

The interaction between precooling treatments and storage days had significant effect on ascorbic acid content during storage. The highest ascorbic acid content (4.51 mg/100g) was recorded in treatment combination P_1 D_1 (Control + 0 days), which was statistically at par with P_2 D_1 (Field cooling + 0 days). However, after 28 days of storage period, the treatment combination of P_3 D_5 (Hydro-cooling + 28 days) recorded highest ascorbic acid content (2.50 mg/100g) and P_1 D_5 (Control + 28 days) recorded lowest ascorbic acid content (1.25 mg/100g).

4.1.12 Anthocyanin content

The data depicted in Table 4.6 revealed that the different precooling treatments and storage days exhibited a significant effect on anthocyanin content. The highest anthocyanin content (1.19 A_{530}-OD) was recorded in treatment P_3 (Hydro-cooling), which was statistically at par with P_4 (Air cooling). However, the lowest anthocyanin content (0.98 A_{530}-OD) was observed in control (P_1) which was statistically at par with treatment P_2 (Field cooling).

With respect to storage days, the maximum anthocyanin content (1.36 A_{530}-OD) was observed in fruit stored in 0 days (D_1), which was significantly followed by fruits stored for 7 days (D_2). The minimum anthocyanin content (0.87 A_{530}-OD) was observed in fruits stored for 28 days (D_5).

Table 4.6 Effect of different precooling treatments and storage duration on ascorbic acid and anthocyanin content of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Ascorbic Acid Content (mg/100g)						Anthocyanin Content (A_{530} -OD)					
	D_1 (0 days)	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**	**D_1 (0 days)**	**D_2 (7 days)**	**D_3 (14 days)**	**D_4 (21 days)**	**D_5 (28 days)**	**Mean (P)**
P_1 (Control)	4.51	2.82	2.19	1.56	1.25	**2.47**	1.33	1.05	0.96	0.85	0.70	**0.98**
P_2 (Field Cooling)	4.44	3.13	2.51	2.19	1.56	**2.77**	1.35	1.14	0.98	0.89	0.74	**1.02**
P_3 (Hydro-Cooling)	4.39	4.07	3.44	3.13	2.50	**3.51**	1.39	1.27	1.14	1.10	1.06	**1.19**
P_4 (Air Cooling)	4.40	3.44	3.13	2.82	1.88	**3.14**	1.36	1.23	1.12	1.08	0.98	**1.16**
Mean (D)	**4.44**	**3.37**	**2.82**	**2.43**	**1.80**		**1.36**	**1.17**	**1.05**	**0.98**	**0.87**	
	$CD_{0.05}$ P – 0.04 D – 0.04 P × D – 0.08						$CD_{0.05}$ P – 0.05 D – 0.06 P × D – NS					

The interaction between precooling treatments and storage days had significant effect on anthocyanin content during storage. The highest anthocyanin content (1.39 A_{530}-OD) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days). However, after 28 days of storage period, the treatment combination of P_3 D_5 (Hydro-cooling + 28 days) recorded highest anthocyanin content (1.06 A_{530}-OD) and P_1 D_5 (Control + 28 days) recorded lowest anthocyanin content (0.70 A_{530}-OD) after 28 days of storage.

4.1.13 Total phenols

The appraisal of data presented in Table 4.7 revealed that the different precooling treatments and storage days exhibited a significant effect on total phenols content. The highest total phenols content (475.82 mg GAE/100 g) was recorded in treatment P_3 (Hydro-cooling). However, the lowest total phenols content (468.69 mg GAE/100 g) was observed in Control (P_1) which was statistically at par with treatment P_2 (Field cooling) and P_4 (Air cooling).

With respect to storage days, the maximum total phenols content (540.37 mg GAE/100 g) was observed in fruit stored in 0 days (D_1), which further decreased with increase in storage time. Further, the fruits stored for 7 days recorded the total phenols content of 512.10 mg GAE/100 g which was highest among other storage time. The minimum total phenols content (413.29 mg GAE/100 g) was observed in fruits stored for 28 days (D_5).

The interaction between precooling treatments and storage days had a significant effect on total phenols content. The highest total phenols content (541.02 mg GAE/100 g) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days), which was statistically at par with P_1 D_1 (Control+ 0 days), P_2 D_1 Field cooling + 0 days) and P_4 D_1 (Air cooling + 0 days). However, after 28 days of storage, the highest total phenols content (427.36 mg/100 g) was recorded in treatment combination P_3D_5 (Hydro-cooling + 28 days) and the lowest total phenols content (405.43 mg/100g) was recorded in P_1 D_5 (Control + 28 days), which was statistically at par with P_2 D_5 (Field cooling + 28 days) and P_4 D_5 (Air cooling + 28 days).

4.1.14 Antioxidant activity

The data depicted in Table 4.7 indicated that the different precooling treatments and storage days exhibited a significant effect on antioxidant activity in fruits during storage. The

highest antioxidant activity (85.39 %) was recorded in treatment P_3 (Hydro-cooling) which was statistically at par with P_4 (Air cooling). However, the lowest antioxidant activity (80.98 %) was observed in Control (P_1).

With respect to increase in storage days, the maximum antioxidant activity showed a decreasing trend in apple during storage. The value varies from 86.95 per cent to 78.30 per cent during storage. The highest fruit antioxidant activity (86.95 %) was observed in fruit stored in 0 days (D_1), which was significantly followed by fruits stored for 7 days and 14 days. The minimum antioxidant activity (78.30 %) was observed in fruits stored for 28 days (D_5).

The interaction between precooling treatments and storage days had a significant effect on antioxidant activity of fruits during storage. The highest antioxidant activity (87.97 %) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days), which was statistically at par with P_2 D_1 (Field cooling + 0 days) and P_4 D_1 (Air cooling + 0 days). However, the antioxidant activity showed decreasing trend with respect to further storage time and precooling treatments. After 28 days of storage, the highest antioxidant activity (82.42 %), which was statistically at par with P_4 D_5 (Air-Cooling + 28 days). The lowest antioxidant activity (73.88 %) was recorded in P_1 D_5 (Control + 28 days), which was statistically at par with P_2 D_5 (Field cooling + 28 days).

The total phenols content and antioxidant activity reduced with the increase in storge days. The highest value among different pre-cooling treatments was in hydro-cooling, significantly followed by air-cooling and minimum in the control. The phenolic compounds are converted to α-quinones and thereafter, polymerized to brown pigments might be the reason of decrease in level of total phenols during storage (Mahajan *et al*., 2023). However, the hydro-cooling might have retained this process to some extent during storage, leading to better phenolic content in comparison to other pre-cooling treatments. The present findings are in confirmatory with those of Hong *et al*. (2018), who also reported maintenance of higher total phenolic compound in strawberries by pre-cooling treatments. Sena *et al*. (2019) also recorded positive effect of hydro-cooling on rate of decline of total phenols in cashew apples. The reduction in antioxidant activity with respect to increase in storage time might be due to loss of membrane integrity and its decompartmentalization, PPO enzymes reacts with phenolic compounds, causing oxidation and polymerization of their compounds (Cheng *et al*., 2015; Fonteles *et al*., 2016).

Table 4.7 Effect of different precooling treatments and storage duration on total phenols content and antioxidant activity of apple cv. Jeromine.

Days (D) / Pre-cooling (P)	Total Phenols (mg GAE/100 g)						Antioxidant Activity (%)					
	D_1 (0 days)	D_2 (7 days)	D_3 (14 days)	D_4 (21 days)	D_5 (28 days)	Mean (P)	D_1 (0 days)	D_2 (7 days)	D_3 (14 days)	D_4 (21 days)	D_5 (28 days)	Mean (P)
P_1 (Control)	539.15	511.66	460.17	427.03	405.43	**468.69**	85.75	84.51	82.62	78.13	73.88	**80.98**
P_2 (Field Cooling)	540.35	512.08	461.60	429.71	407.57	**470.26**	86.80	85.36	83.75	80.90	75.05	**82.37**
P_3 (Hydro-Cooling)	541.02	512.38	463.16	435.19	427.36	**475.82**	87.97	86.31	85.26	84.97	82.42	**85.39**
P_4 (Air Cooling)	540.95	512.29	462.04	430.71	412.81	**471.76**	87.30	86.17	84.81	83.35	81.86	**84.70**
Mean (D)	**540.37**	**512.10**	**461.74**	**430.66**	**413.29**		**86.95**	**85.59**	**84.11**	**81.84**	**78.30**	
	$CD_{0.05}$ P – 3.39 D – 3.78 P × D – 7.57						$CD_{0.05}$ P – 0.89 D – 0.99 P × D – 1.98					

The hydro-cooling and air-cooling treatment results in lower physiological loss in weight (Table 4.1), which would have resulted lesser oxidation of phenolic compounds and would have retained higher antioxidant activity in these fruits in comparison to other treatments. The results are in accordance with those of Diaz-Mula *et al*. (2013) who also maintained higher antioxidant activity in pre-cooled 'Sonata' Sweet Cherry in comparison to non-cooled cherry.

4.2 EXPERIMENT NO. II: - Studies on the storability of exotic cultivars of apple under different storage conditions

4.2.1 Fruit weight

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on fruit weight recorded during 2022 is depicted in Table 4.8. The perusal of data presented in Table 4.8 revealed that the different cultivars, storage temperatures and storage duration exhibited a significant effect on fruit weight. Among the cultivars, the highest fruit weight (109.22 g) was observed in C_1 (Jeromine). However, the lowest fruit weight (86.88 g) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest fruit weight (102.41 g) was recorded in T_1 (0°C). However, the lowest fruit weight (93.65 g) was recorded in T_3 (Room temperature). Among different storage duration, the fruit weight showed decreasing trend with respect to increase in storage duration. The maximum fruit weight (114.68 g) was observed in D_1 (0 day) and the minimum fruit weight (84.34 g) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on fruit weight (Table 4.8.). In case of interaction between cultivars and storage temperature, the maximum fruit weight (113.67 g) was recorded in treatment combination of C_1 T_1 (Jeromine + 0°C) and minimum fruit weight (82.15 g) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage duration the highest fruit weight (125.29 g) was recorded in Jeromine cultivar stored at 0 days, which further decrease with increase in storage duration for 45 days. After 45 days of storage, the highest fruit weight (94.93 g) was recorded in cultivar Jeromine (C_1 D_4) and lowest fruit weight (73.76 g) was observed in Redlum Gala cultivar (C_2 D_4).

Considering the interaction between storage temperature and storage duration, the significantly highest fruit weight (115.07 g) was observed in T_1 D_1 (0°C + 0 day) which was statistically at par with T_3 D_1 (Room Temperature + 0 day). Further the fruit weight variably decreases with respect to increase in storage duration up to 45 days. The highest fruit weight (91.72 g) was observed in T_1 D_4 (0°C + 45 days) and lowest was recorded in T_3 D_4 (Room Temperature + 45 days) having fruit weight of 76.47 g after 45 days of storage.

Among three factor interactions, the highest fruit weight (126.09 g) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). Further the fruit weight decreases with increasing storage duration up to 45 days with respect of storage temperature and cultivars. After 45 days of storage, the highest fruit weight (104.00 g) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days) having fruit weight of 66.16 g.

Table 4.8. Effect of different cultivars, storage duration and temperatures on fruit weight of apple during storage

C / T / D	Fruit weight (g)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	126.09	125.03	124.76	**125.29**	104.05	103.07	105.07	**104.06**
D_2(15 days)	116.32	112.69	110.47	**113.16**	94.67	90.94	81.40	**89.00**
D_3(30 days)	108.27	103.67	98.59	**103.51**	86.41	79.65	75.99	**80.68**
D_4(45 days)	104.00	94.00	86.79	**94.93**	79.44	75.68	66.16	**73.76**
Mean(C×T)	**113.67**	**108.85**	**105.15**		**91.14**	**87.33**	**82.15**	
	Mean (C_1) 109.22				**Mean (C_2) 86.88**			

T / D	T × D			Mean (D)
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	
D_1 (0 day)	115.07	114.05	114.91	**114.68**
D_2(15 days)	105.50	101.82	95.94	**101.08**
D_3(30 days)	97.34	91.66	87.29	**92.10**
D_4(45 days)	91.72	84.84	76.47	**84.34**
Mean(T)	**102.41**	**98.09**	**93.65**	

$CD_{0.05}$	
C	0.41
T	0.51
D	0.59
C×T	0.72
C×D	0.83
T×D	1.01
C×T×D	1.43

C – Cultivars; T – Storage Temperatures; D – Storage duration

4.2.2 Physiological loss in weight

The data depicted in Table 4.9 revealed that the different cultivars, storage temperatures and storage duration had significant effect on physiological loss in weight during storage of apple fruits (Plate 4 and 5).

The perusal of data presented in Table 4.9 revealed that different cultivars, storage temperatures and storage duration exhibited a significant effect on physiological loss in

weight during storage. Among the cultivars, the highest physiological loss in weight (16.49 %) was observed in C_2 (Redlum Gala). However, the lower physiological loss in weight (12.84 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest physiological loss in weight (18.76 %) was recorded in T_3 (Room temperature). However, the lowest physiological loss in weight (11.13 %) was recorded in T_1 (0°C). Among the storage duration, the maximum physiological loss in weight (26.67 %) was observed in D_4 (45 days). However, no physiological loss in weight was observed in D_1 (0 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on physiological loss in weight (Table 4.9). In case of interaction between cultivars and storage temperature, the maximum physiological loss in weight (21.81 %) was recorded in C_2 T_3 (Redlum Gala + Room Temperature) and minimum physiological loss in weight (9.85 %) was recorded in C_1 T_1 (Jeromine + 0°C). Among the interaction between cultivars and storage duration, no physiological loss in weight was recorded during 0 days (D_4). However, as the storage days increased the physiological loss in weight showed increasing trend. After 45 days of storage, the highest physiological loss in weight (29.09 %) was recorded in Redlum Gala cultivar (C_2 D_4) and lowest physiological loss in weight (24.26 %) was recorded in Jeromine cultivar (C_1 D_4) stored for 45 days. Considering, the interaction between storage temperature and storage duration, the highest physiological loss in weight (33.74 %) was observed in T_3 D_4 (Room Temperature + 45 days). Further, with respect to prolonging storage period, the physiological loss in weight showed increasing trend, and lowest physiological loss in weight after 45 days of storage (20.59 %) was recorded in fruits stored at 0°C (T_1 D_4). Among three factor interactions, the highest physiological loss in weight (37.04 %) was recorded in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days), no physiological loss in weight was recorded in 0 days (D_1) with respect both the cultivars and all temperatures. However, after 45 days of storage, treatment combination C_1 T_1 D_4 (Jeromine + 0°C + 45 days) recorded lowest physiological loss in weight of 17.52 per cent.

The result from the present study indicate that the fruit weight had an inverse relationship with increased storage period, whereas physiological loss in weight exhibited a linear relationship with prolonging storage period. This increase in loss in weight on prolonging storage period might be attributed to the rapid loss of moisture through evapo-transpiration and respiration (Maini *et al*., 1983, Ghafir *et al.,* 2009). Further, the moisture

loss decreases the visual quality and contributes to the loss of turgor pressure and subsequent softening of fruits (Chien *et al.,* 2005). The Redlum Gala showed higher physiological loss in weight in comparison to Jeromine, as this variation in loss in weight among cultivars may also be attributed to genetical texture and skin characteristics (Veraverbeke *et al*., 2001; Singh *et al*., 2003). The present findings are in line with those of (Farooq *et al*., 2012), who also reported increase in rate of weight loss with increasing storage duration in apple cultivar Gala Must. Kishor *et al.* (2018) also reported increase in physiological loss in weight during storage in apple cultivars (Golden Delicious, Skyline Supreme, Bright-N- Early, Top Red, Starkrimson, Red Spur, Oregon Spur, Rich-a-Red and Red Delicious). The lower temperature (0°C) resulted in lower weight loss in fruit during storage in comparison to 4 °C and room temperature (20-22°C), however, increases with storage period. Similarly, Pandey *et al*. (2006) have also reported increase in physiological loss in weight in apple following storage either room temperature or in cold storage.

Table 4.9 Effect of different cultivars, storage duration and temperatures on physiological loss in weight (% -PLW) in apple during storage

C / T / D	Physiological loss in weight (%-PLW)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	0 (0.00)*	0 (0.00)	0 (0.00)	**0 (0.00)**	0 (0.00)	0 (0.00)	0 (0.00)	**0 (0.00)**
D_2(15 days)	7.75 (16.14)	9.87 (18.30)	11.45 (19.77)	**9.69 (18.07)**	9.01 (17.46)	11.75 (20.01)	22.52 (28.31)	**14.43 (21.93)**
D_3(30 days)	14.14 (22.08)	17.08 (24.39)	20.98 (27.24)	**17.40 (24.57)**	16.95 (24.29)	22.72 (28.45)	27.67 (31.73)	**22.45 (28.16)**
D_4(45 days)	17.52 (24.73)	24.82 (29.87)	30.44 (33.47)	**24.26 (29.35)**	23.65 (29.08)	26.57 (31.01)	37.04 (37.47)	**29.09 (32.52)**
Mean(C×T)	**9.85 (15.74)**	**12.94 (18.14)**	**15.72 (20.12)**		**12.40 (17.71)**	**15.26 (19.87)**	**21.81 (24.38)**	
	Mean (C_1) 12.84 (18.00)				**Mean (C_2) 16.49 (20.65)**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	0 (0.00)	0 (0.00)	0 (0.00)	**0 (0.00)**	C	0.38
D_2(15 days)	8.38 (16.80)	10.81 (19.16)	16.99 (24.04)	**12.06 (20.00)**	T	0.47
D_3(30 days)	15.54 (23.18)	19.90 (26.42)	24.33 (29.49)	**19.92 (26.36)**	D	0.54
D_4(45 days)	20.59 (26.90)	25.69 (30.44)	33.74 (35.47)	**26.67 (30.94)**	C×T	0.67
Mean(T)	**11.13 (16.72)**	**14.10 (19.00)**	**18.76 (22.25)**		C×D	0.77
					T×D	0.94
					C×T×D	1.33

*** Data in parenthesis are angularly transformed values. C – Cultivars; T – Storage Temperatures; D – Storage duration.**

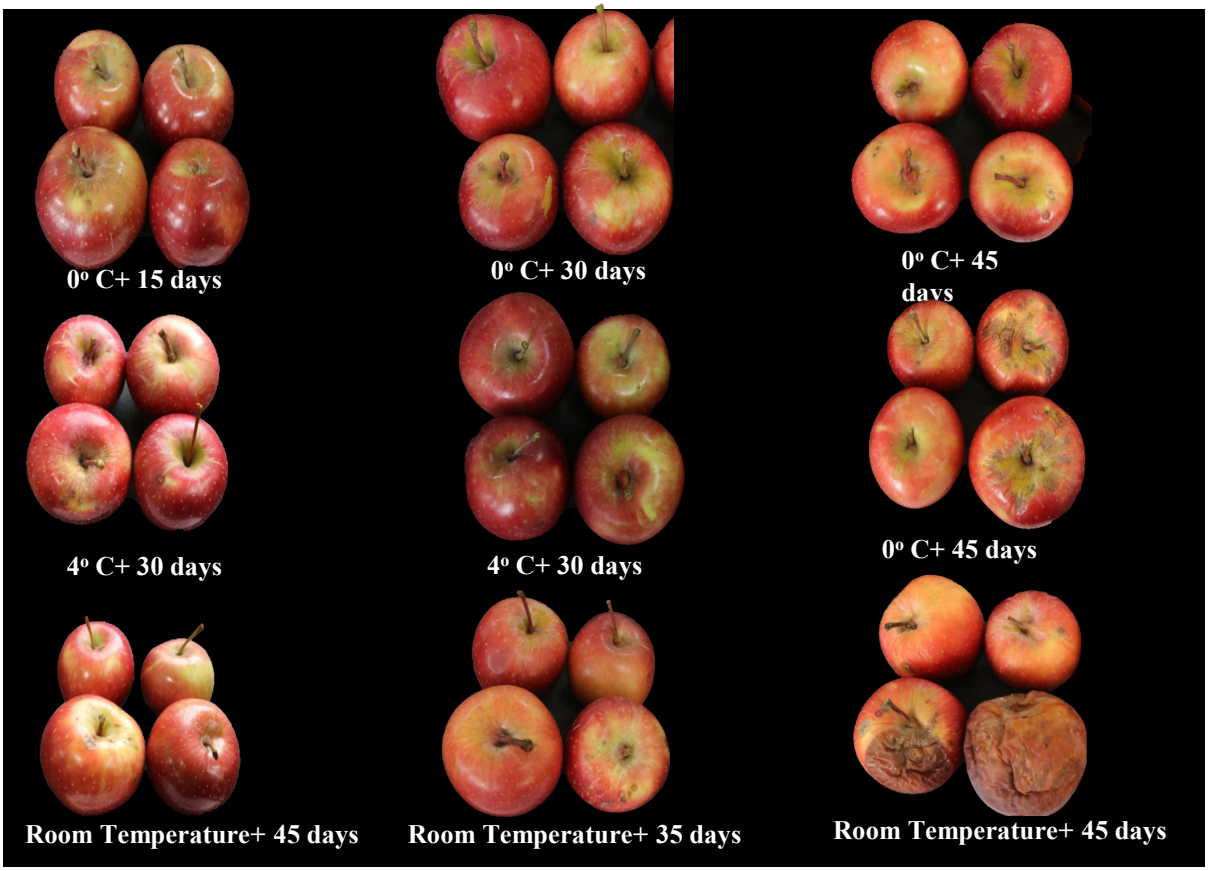


Plate 4. Effect of different storage time and duration on fruit physiological loss in weight of apple cv. Jeromine

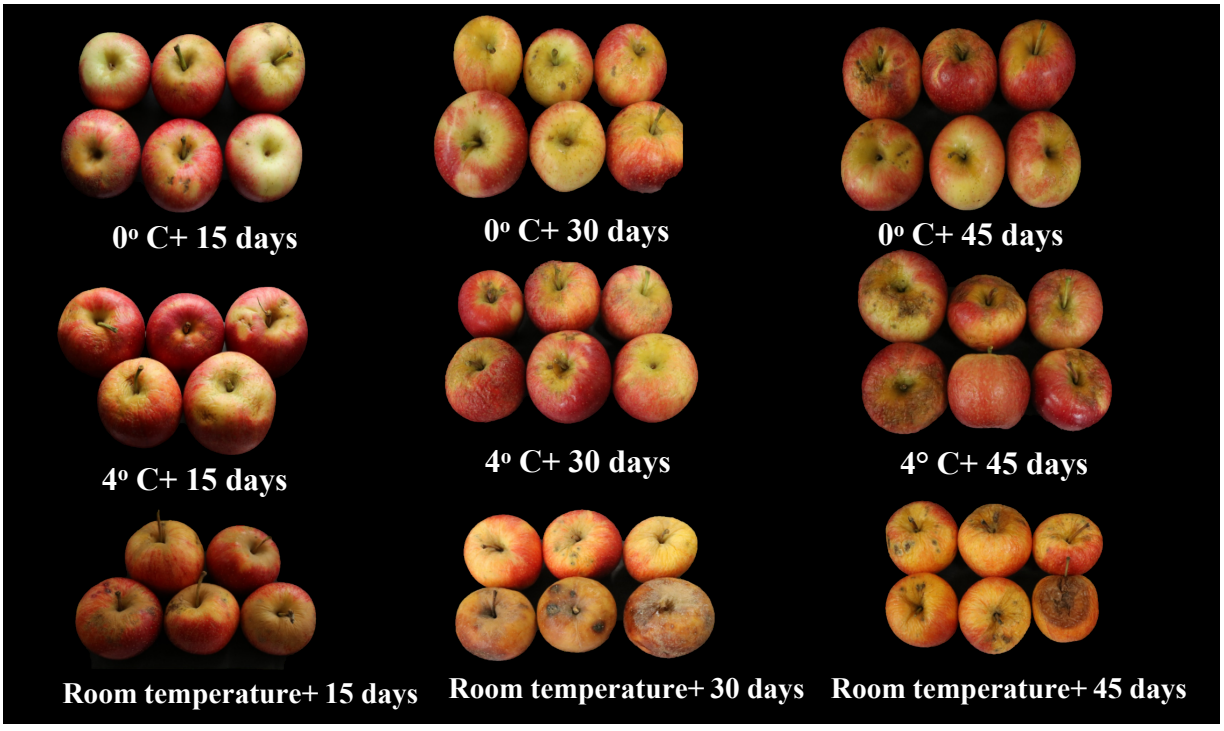


Plate 5. Effect of different storage time and duration on fruit physiological loss in weight of apple cv. Redlum Gala

As temperature management is one of the most important tool for extending the shelf-life of fruits (Lee and Kader, 2000). Hence, storage of fruits at low temperature, had a direct effect on the rate of chemical reaction, resulting in a slowing the rate of metabolism, delaying senescence. The results of the present findings are in confirmatory with those of Khorshidi *et al*. (2010) who also recorded minimum weight loss percentage in apple cv. Red Delicious stored at 0°C in comparison to fruits stored at 5°C and 12°C.

4.2.3 Fruit Volume

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on fruit volume recorded during 2022 is depicted in Table 4.10. It is inferred from the data that cultivars, storage temperatures and storage duration and their interactions had a significant effect on fruit volume of apple during storage.

The data presented in Table 4.10 revealed that different cultivars, storage temperatures and storage duration exhibited significant effect on fruit volume of apple under storage. Among the cultivars, the highest fruit volume (121.54 cc) was observed in C_1 (Jeromine) and the lowest fruit volume (98.72 cc) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest fruit volume (115.28 cc) was recorded in T_1 (0°C) and the lowest fruit volume (104.75 cc) was recorded in T_3 (Room temperature). With respect to different storage duration the fruit volume showed decreasing trend with respect to prolonging storage period. The maximum fruit volume (130.62 cc) was observed in D_1 (0 day) and the minimum fruit volume (93.67 cc) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration and storage temperature and storage duration were found significant on fruit volume (Table 4.10.). In case of interaction between cultivars and storage temperature, the maximum fruit volume (128.63 cc) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum fruit volume (94.50 cc) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage duration, the highest fruit volume (143.16 cc) was recorded in Jeromine cultivar stored at 0 days, which further decrease with increase in storage duration for 45 days. After 45 days of storage, the highest fruit volume (103.41 cc) was recorded in cultivar Jeromine and lowest fruit volume (83.94 cc) was observed in Redlum Gala cultivar. Considering the interaction between storage temperature and storage duration, the significantly highest fruit volume (131.29 cc) was observed in T_1 D_1 (0°C + 0 day) which was

statistically at par with T_2 D_1 (4°C + 0 day) and T_3 D_1 (Room Temperature + 0 day). Further the fruit volume variably decreases with respect to increase in storage duration and different temperatures. After 45 days of storage, the highest fruit volume (101.33 cc) was observed in T_1 D_4 (0°C + 45 days) and lowest was found in T_3 D_4(Room Temperature + 45 days) having fruit volume of 84.45 cc. Among three factor interactions, the highest fruit volume (144.91 cc) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day) which was statistically at par with C_1 T_2 D_1 (Jeromine + 4°C + 0 day) and C_1 T_3 D_1 (Jeromine + Room Temperature + 0 day). The fruit volume decreases with increasing storage duration with respect of storage temperature and cultivars. The highest fruit volume (113.33 cc) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest fruit volume (76.33 cc) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

Table 4.10 Effect of different cultivars, storage duration and temperatures on fruit volume of apple during storage

C / T / D	Fruit Volume (cc)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	144.91	143.00	141.58	**143.16**	117.67	117.21	119.32	**118.07**
D_2(15 days)	130.93	124.00	120.79	**125.24**	105.19	101.76	94.86	**100.60**
D_3(30 days)	125.33	112.67	105.03	**114.34**	95.56	93.73	87.51	**92.26**
D_4(45 days)	113.33	104.33	92.56	**103.41**	89.33	86.16	76.33	**83.94**
Mean(C×T)	**128.63**	**121.00**	**114.99**		**101.94**	**99.72**	**94.50**	
	Mean (C_1) 121.54				**Mean (C_2) 98.72**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	131.29	130.11	130.45	**130.62**	C	1.02
D_2(15 days)	118.06	112.88	107.83	**112.92**	T	1.25
D_3(30 days)	110.45	103.20	96.27	**103.30**	D	1.44
D_4(45 days)	101.33	95.25	84.45	**93.67**	C×T	1.77
Mean(T)	**115.28**	**110.36**	**104.75**		C×D	2.04
					T×D	2.50
					C×T×D	3.53

C – Cultivars; T – Storage Temperatures; D – Storage duration

4.2.4 Fruit density

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on fruit density recorded during 2022 is depicted in Table 4.11. The perusal of data presented in Table 4.11 reveals that cultivars and storage duration exhibited significant effect on fruit density, however, the storage temperature had non-significant effect on fruit density. Among the cultivars, the higher fruit density (0.902 g/cc) was observed in C_1 (Jeromine) and lowest fruit density (0.880 g/cc) was observed in C_2 (Redlum Gala). Among

different storage duration, the highest fruit density (0.899 g/cc) was recorded in D_4 (45 days) which was statistically at par with D_2 (15 days) and D_3 (30 days). However, the lowest fruit density (0.878 g/cc) was recorded in D_1 (Room temperature) which was statistically at par with D_3 (30 days). The storage temperature exerted a non-significant effect on fruit density of apple under storage.

The interaction between different cultivars and storage temperature, cultivars and storage duration, and cultivars, storage temperature and storage duration showed significant effect on fruit density, however, the interaction between storage temperature and storage duration was found non-significant on fruit density (Table 4.11). In case of interaction between cultivars and storage temperature, the maximum fruit density (0.918 g/cc) was recorded in C_1 T_3 (Jeromine + Room Temperature) and minimum fruit density (0.869 g/cc) was recorded in C_2 T_3 (Redlum Gala + Room Temperature) which was statistically at par with C_2 T_2 (Redlum Gala + 4°C).

Among the interaction between cultivars and storage duration the highest fruit density (0.919 g/cc) was recorded in Jeromine cultivar stored for 45 days which was statistically at par with C_1 D_2 (Jeromine + 15 days) and C_1 D_3 (Jeromine + 30 days) and lowest fruit density (0.874 g/cc) in C_2 D_3 (Redlum Gala + 30 days), which was statistically at par with C_2 D_1 (Redlum Gala + 0 days), C_2 D_2 (Redlum Gala + 15 days) and C_2 D_4 (Redlum Gala + 45 days).

Table 4.11 Effect of different cultivars, storage duration and temperatures on fruit density of apple during storage

C / T / D	Fruit Density (g/cc)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	0.870	0.874	0.881	**0.875**	0.884	0.879	0.881	**0.881**
D_2(15 days)	0.889	0.909	0.915	**0.904**	0.901	0.893	0.858	**0.884**
D_3(30 days)	0.864	0.920	0.939	**0.908**	0.905	0.850	0.869	**0.874**
D_4(45 days)	0.918	0.901	0.938	**0.919**	0.890	0.879	0.867	**0.879**
Mean(C×T)	**0.885**	**0.901**	**0.918**		**0.895**	**0.875**	**0.869**	
	Mean (C_1) 0.902				**Mean (C_2) 0.880**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	0.877	0.877	0.881	**0.878**	C	0.009
D_2(15 days)	0.895	0.901	0.886	**0.894**	T	NS
D_3(30 days)	0.884	0.885	0.904	**0.891**	D	0.013
D_4(45 days)	0.904	0.890	0.903	**0.899**	C×T	0.016
Mean(T)	**0.890**	**0.888**	**0.894**		C×D	0.018
					T×D	NS
					C×T×D	0.032

C – Cultivars; T – Storage Temperatures; D – Storage duration

Considering the interaction between storage temperature and storage duration, the highest fruit density (0.904 g/cc) was observed in T_1 D_4 (0°C + 45 days) and T_3 D_3 (Room Temperature + 30 days) and lowest was observed in T_1 D_1 (0°C + 0 days) and T_2 D_1 (4°C + 0 days) having fruit density of 0.877 g/cc.

Among three factor interactions, the highest fruit density (0.939 g/cc) was recorded in C_1 T_3 D_3 (Jeromine + Room Temperature + 30 days) which was statistically at par with C_1 T_3 D_2 (Jeromine + Room Temperature + 15 days) and C_1 T_3 D_4 (Jeromine + Room Temperature (20-22°C) + 45 days) and lowest fruit density (0.850 g/cc) in C_2 T_2 D_3 (Redlum Gala + 4°C + 30 day) which was statistically at par with C_2 T_2 D_4 (Redlum Gala + 4°C + 45 days).

4.2.5. Firmness

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on fruit firmness recorded during 2022 is presented in Table 4.12.

The perusal of data presented in Table 4.12 revealed that different cultivars, storage temperatures and storage duration exhibited significant effect on fruit firmness in apple during storage. Among the cultivars, the highest fruit firmness (6.41 kg/cm^2) was observed in C_1 (Jeromine) and the lowest fruit firmness (5.22 kg/cm^2) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest fruit firmness (6.77 kg/cm^2) was recorded in T_1 (0°C) and the lowest fruit firmness (4.43 kg/cm^2) was recorded in T_3 (Room temperature). The fruit firmness decreases with increase in storage duration. Among the storage duration, the maximum fruit firmness (7.89 kg/cm^2) was observed in D_1 (0 day) and the minimum fruit firmness (4.14 kg/cm^2) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on fruit firmness of apple fruit under storage (Table 4.12). In case of interaction between cultivars and storage temperature, the maximum fruit firmness (7.41 kg/cm^2) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum fruit firmness (3.92 kg/cm^2) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage duration the highest fruit firmness (8.62 kg/cm^2) was recorded in Jeromine cultivar stored at 0 days (C_1 D_1), which further decrease with increase in storage duration for 45 days. However, after 45 days of storage, the highest fruit firmness (4.59

kg/cm^2) was recorded in cultivar Jeromine (C_1 D_4) and the lowest fruit firmness (3.70 kg/cm^2) was recorded in Redlum Gala cultivar (C_2 D_4).

Considering the interaction between storage temperature and storage duration, the significantly highest firmness (8.01 kg/cm^2) was observed in T_1 D_1 (0°C + 0 day). Further the fruit firmness variably decreases with respect to increase in storage duration. However, after 45 days of storage, the highest fruit firmness (5.54 kg/cm^2) was observed in T_1 D_4 (0°C + 45 days) and lowest was observed in T_3 D_4 (Room Temperature + 45 days) having fruit firmness of 2.29 kg/cm^2. Among three factor interactions, the highest fruit firmness (8.75 kg/cm^2) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). Further the fruit firmness decreases with increasing storage duration with respect of storage temperature and cultivars. After 45 days of storage, the highest fruit firmness (6.07 kg/cm^2) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest fruit firmness (1.98 kg/cm^2) was recorded in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

The results from the present investigation revealed that the fruit firmness varies with respect to cultivars, storage duration and temperature. Jeromine accounted for more firmness during storage with respect to duration and temperature in comparison to Redlum Gala. This might be due to Jeromine being genetically more amenable to storage than Redlum Gala. Similarly, Lu *et al*. (2021) also reported that apple cultivar 'Meihong' fruits were more amenable to storage than 'Golden Delicious' fruits and further these two cultivars also vary regarding their ability to synthesize ethylene. The fruit firmness decreases with prolonged storage period, which might be due to water loss during storage caused by respiration and cell wall breakdown due to enzymatic activities (Kweon *et al*., 1998). The water loss directly affects turgidity of cells (Ghafir *et al*., 2009) and further cell wall changes influence the firmness of apple fruit by reducing the mechanical strength of cell walls (Chang- Hai *et al*., 2006). The present findings are in line with those of (Farooq *et al*., 2012), who also recorded decreasing trend in fruit firmness from maximum (7.03 kg/cm^2) in fresh fruits to minimum of 4.31 kg/cm^2 with storage of 150 days in apple cv. Gala Must. Under storage condition, similarly, Kishor *et al*. (2018) also observed decrease in fruit firmness of apple cultivars with respect to prolonging storage period under ambient conditions. Low temperature storage at 0°C resulted in lower decrease in fruit firmness with respect to storage period in comparison to fruit stored at 4°C and room temperature. The reason might be the fruit stored at low temperature significantly delays the release of ethylene. This changes to ethylene content

considerably influenced fruit firmness and fruit softening related enzyme activities (Wei *et al.,* 2010; Zhang *et al*., 2015). The present findings are in confirmatory with those of Khorshidi *et al*., (2010) who also recorded firmer fruits of apple cv. Red Delicious stored in lower temperature than fruits stored in higher temperatures. Lu *et al.,* (2021) observed apple cultivar 'Meihong' stored at low temperature (0 ± 5°C) delayed fruit softening in comparison to fruits stored at room temperature (20-25°C).

Table 4.12 Effect of different cultivars, storage duration and temperatures on fruit firmness of apple during storage

C / T / D	Fruit firmness (kg/cm^2)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	8.75	8.68	8.43	**8.62**	7.26	7.17	7.02	**7.15**
D_2(15 days)	7.86	7.38	5.02	**6.75**	6.57	6.17	4.11	**5.62**
D_3(30 days)	6.97	6.40	3.68	**5.68**	5.62	5.03	2.58	**4.41**
D_4(45 days)	6.07	5.09	2.61	**4.59**	5.01	4.10	1.98	**3.70**
Mean(C×T)	**7.41**	**6.89**	**4.94**		**6.12**	**5.62**	**3.92**	
	Mean (C_1) 6.41				**Mean (C_2) 5.22**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	8.01	7.93	7.73	**7.89**	C	0.01
D_2(15 days)	7.22	6.78	4.57	**6.19**	T	0.02
D_3(30 days)	6.30	5.72	3.13	**5.05**	D	0.02
D_4(45 days)	5.54	4.60	2.29	**4.14**	C×T	0.02
Mean(T)	**6.77**	**6.25**	**4.43**		C×D	0.03
					T×D	0.03
					C×T×D	0.05

C- Cultivars; T- Storage Temperatures; D – Storage Duration

4.2.6 Total Soluble Solids

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on total soluble solids content recorded during 2022 is presented in Table 4.13.

The perusal of data depicted in Table 4.13 revealed that different cultivars, storage temperatures and storage duration exhibited a significant effect on total soluble solids content of apple during storge. Among the cultivars, the highest total soluble solids content (13.21 °B) was observed in C_2 (Redlum Gala) and the lowest total soluble content (11.12 °B) was observed in C_1 (Jeromine). In case of storage temperatures, the highest total soluble content (12.42 °B) was recorded in T_1 (0°C) and lowest total soluble solids content (11.91 °B) was recorded in T_3 (Room Temperature). With respect to increase in storage duration, the total soluble solids content in apple exhibited an increasing trend. Among the storage duration the

maximum total soluble solids content (13.39 °B) was observed in D_3 (30 days) which was statistically at par with D_4 (45 days). However, the minimum total soluble solids content (10.16 °B) was observed in D_1 (0 day).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration was significant on total soluble solids content of apple during storage (Table 4.13).

In case of interaction between cultivars and storage temperature, the maximum total soluble solids content (13.52 °B) was recorded in C_2 T_1 (Redlum Gala + 0°C) and minimum total soluble solids content (10.96 °B) was recorded in C_1 T_3 (Jeromine + Room Temperature). Among the interaction between cultivars and storage duration, the highest total soluble solids content (14.61 °B) was recorded in cultivar Redlum Gala stored for 45 days (C_2 D_4) and lowest total soluble solids content (8.65 °B) was recorded in Jeromine cultivar stored for 0 days (C_1 D_1). Considering the interaction between storage temperature and storage duration, the highest total soluble solids content (14.53 °B) was observed in T_1 D_4 (0°C + 45 days) and lowest was recorded in T_1 D_1 (0°C + 0 days) having total soluble solids content of 10.07 °B.

Table 4.13 Effect of different cultivars, storage duration and temperatures on total soluble solids (TSS) content of apple during storage

C / T / D	TSS (°B)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	8.50	8.53	8.92	**8.65**	11.63	11.78	11.57	**11.66**
D_2(15 days)	10.37	10.70	11.30	**10.79**	12.57	12.44	12.97	**12.66**
D_3(30 days)	13.13	12.96	12.57	**12.89**	14.06	13.89	13.73	**13.89**
D_4(45 days)	13.27	12.09	11.07	**12.14**	15.80	14.90	13.13	**14.61**
Mean(C×T)	**11.32**	**11.07**	**10.96**		**13.52**	**13.25**	**12.85**	
	Mean (C_1) 11.12				**Mean (C_2) 13.21**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	**T_2 (4°C)**	**T_3 (Room Temperature)**		C	0.06		
D_1 (0 day)	10.07	10.16	10.25	**10.16**	T	0.07		
D_2(15 days)	11.47	11.57	12.13	**11.72**	D	0.08		
D_3(30 days)	13.60	13.43	13.15	**13.39**	C×T	0.10		
D_4(45 days)	14.53	13.50	12.10	**13.38**	C×D	0.12		
Mean(T)	**12.42**	**12.16**	**11.91**		T×D	0.15		
					C×T×D	0.21		

C- Cultivars; T- Storage Temperatures; D – Storage Duration

The three factor interaction between cultivars, storage duration and temperatures exhibited a significant effect on fruit total soluble solids contents during storage. The total soluble solids content increases with prolonging storage duration up to 45 days with respect of cultivars as well as temperature. After 45 days of storage, the highest total soluble solids content (15.80 °B) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest total soluble solids content (11.07 °B) was recorded in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days).

4.2.7 Titratable acidity

The data tabulated in Table 4.14 indicated that the different cultivars, storage temperatures, storage duration and their interactions had significant effect on titratable acidity. Regarding cultivars, highest titratable acidity (0.32 %) was recorded in Jeromine (C_1) and lowest titratable acidity (0.19 %) was found in Redlum Gala (C_1). With respect to storage temperatures, the highest titratable acidity (0.27 %) was recorded in T_1 (0°) which was statistically at par with T_2 (4°C) and lowest titratable acidity (0.24 %) in T_3 (Room Temperature). Among different storage duration, the titratable acidity showed decreasing trend with respect to increase in storage duration. The maximum titratable acidity (0.35 %) was observed in D_1 (0 day) and the minimum titratable acidity (0.19 %) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on titratable acidity (Table 4.14). In case of interaction between cultivars and storage temperature, the maximum titratable acidity (0.34 %) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum titratable acidity (0.18 %) was recorded in C_2 T_3 (Redlum Gala + Room Temperature) which was statistically at par with C_2 T_2 (Redlum Gala + 4°C). Among the interaction between cultivars and storage duration, the highest titratable acidity (0.46 %) was recorded in Jeromine cultivar stored at 0 days (C_1 D_1), which further decrease with increase in storage duration for 45 days. However, after 45 days of storage, the highest titratable acidity (0.22 %) was recorded in cultivar Jeromine C_1 D_4 (Jeromine + 45 days) and lowest titratable acidity (0.15 %) was recorded in Redlum Gala cultivar C_2 D_4 (Redlum Gala + 45 days). Considering the interaction between storage temperature and storage duration, the significantly highest titratable acidity (0.36 %) was

observed in T_2 D_1 (4°C + 0 day). Further the titratable acidity variably decreases with respect to increase in storage duration. After 45 days of storage, the highest titratable acidity (0.21 %) was observed in T_1 D_4 (0°C + 45 days) and lowest in T_3 D_4 (Room Temperature + 45 days) having titratable acidity of 0.17 per cent.

Among three factor interactions, the highest titratable acidity (0.48 %) was recorded in C_1 T_2 D_1 (Jeromine + 4°C + 0 day) which was statistically at par with C_1 T_1 D_1 (Jeromine + 0°C + 0 day). The titratable acidity decreases with increasing storage duration with respect of storage temperature and cultivars. After 45 days of storage, the highest titratable acidity (0.24 %) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest titratable acidity (0.13 %) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

Table 4.14 Effect of different cultivars, storage duration and temperatures on titratable acidity content of apple during storage

C / T / D	Titratable Acidity (%)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	0.47	0.48	0.45	**0.46**	0.22	0.24	0.23	**0.23**
D_2(15 days)	0.36	0.33	0.31	**0.33**	0.21	0.20	0.19	**0.20**
D_3(30 days)	0.28	0.26	0.24	**0.26**	0.19	0.18	0.16	**0.18**
D_4(45 days)	0.24	0.22	0.20	**0.22**	0.18	0.15	0.13	**0.15**
Mean(C×T)	**0.34**	**0.32**	**0.30**		**0.20**	**0.19**	**0.18**	
	Mean (C_1) 0.32				**Mean (C_2) 0.19**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	0.01
					T	0.01
					D	0.01
D_1 (0 day)	0.34	0.36	0.34	**0.35**	C×T	0.01
D_2(15 days)	0.29	0.27	0.25	**0.27**	C×D	0.01
D_3(30 days)	0.23	0.22	0.20	**0.22**	T×D	0.01
D_4(45 days)	0.21	0.19	0.17	**0.19**	C×T×D	0.01
Mean(T)	**0.27**	**0.26**	**0.24**			

C- Cultivars; T- Storage Temperatures; D – Storage Duration

4.2.8 Total sugars (%)

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on total sugars content recorded during 2022 is depicted in Table 4.15. The perusal of data presented in Table 4.15 revealed that different cultivars, storage temperatures and storage duration exhibited a significant effect on total sugars content of apple cultivars during storage. Among the cultivars, the highest total sugars content (8.41 %) was observed in C_2 (Redlum Gala) and the lower total sugars content (7.17 %) was observed

in C_1 (Jeromine). In case of storage temperatures, the highest total sugars content (8.44 %) was recorded in T_1 (0°C) and the lowest total sugars content (7.22 %) was recorded in T_3 (Room temperature). With respect to different storage duration, the total sugars content showed an increasing trend with respect to increase in storage duration. The minimum total sugar content (6.15 %) was observed in D_1 (0 day) and the maximum total sugar content (9.33 %) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on total sugars content. (Table 4.15). In case of interaction between cultivars and storage temperature, the maximum total sugars content (9.35 %) was recorded in C_2 T_1 (Redlum Gala + 0°C) and minimum total sugars content (6.90 %) was recorded in C_1 T_3 (Jeromine + Room Temperature).

Table 4.15 Effect of different cultivars, storage duration and temperatures on total sugars content of apple during storage

C / T / D	Total Sugars (%)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	5.87	5.95	5.85	**5.89**	6.40	6.42	6.38	**6.40**
D_2(15 days)	7.20	7.11	6.95	**7.08**	9.37	7.79	7.57	**8.24**
D_3(30 days)	7.48	7.30	7.08	**7.28**	10.12	8.34	7.79	**8.75**
D_4(45 days)	9.57	7.98	7.73	**8.43**	11.51	10.77	8.39	**10.22**
Mean(C×T)	**7.53**	**7.09**	**6.90**		**9.35**	**8.33**	**7.53**	
	Mean (C_1) 7.17				**Mean (C_2) 8.41**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	**T_2 (4°C)**	**T_3 (Room Temperature)**		C	0.02		
D_1 (0 day)	6.14	6.19	6.12	**6.15**	T	0.02		
D_2(15 days)	8.29	7.45	7.26	**7.66**	D	0.03		
D_3(30 days)	8.80	7.82	7.43	**8.02**	C×T	0.02		
D_4(45 days)	10.54	9.38	8.06	**9.33**	C×D	0.03		
Mean(T)	**8.44**	**7.71**	**7.22**		T×D	0.04		
					C×T×D	0.06		

C- Cultivars; T- Storage Temperatures; D – Storage Duration

With respect to the interaction between cultivars and storage duration, total sugars contents increased with increase in storage duration with respect to different cultivars. After 45 days of storage, the highest total sugars content (10.22 %) was recorded in cultivar Redlum Gala (C_2 D_4) and lowest total sugar content (8.43 %) was recorded in Jeromine cultivar (C_1 D_4). Considering the interaction between storage temperature and storage

duration, the total sugars content variably increased with respect to increase in storage duration, with respect to different temperatures. However, after 45 days of storage, the highest total sugars content (10.54 %) was observed in T_1 D_4 (0°C + 45 days) and lowest in T_3 D_4 (Room Temperature + 45 days) having total sugars content of 8.06 per cent.

Among three factor interactions, of cultivars, storage duration and storage temperatures, the total sugars content increased with increasing storage duration with respect of storage temperature and cultivars. After 45 days of storage, the highest total sugars content (11.51 %) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days) having total sugars content of 7.73 per cent.

4.2.9 Reducing sugars

The perusal of data presented in Table 4.16 revealed that different cultivars, storage temperatures and storage duration exhibited a significant effect on reducing sugars content of apple fruits during storage. Among the cultivars, the highest reducing sugars content (6.25 %) was observed in C_2 (Redlum Gala) and the lowest reducing sugars content (5.34 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest reducing sugar content (6.25 %) was recorded in T_1 (0°C) and the lowest reducing sugars content (5.47 %) was recorded in T_3 (Room temperature). With respect to different storage duration, the reducing sugars content showed increasing trend with respect to prolonging in storage period. The minimum reducing sugars content (3.81 %) was observed in D_1 (0 day) and the maximum reducing sugars content (7.24 %) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration was found significant on reducing sugars content of apple under storage (Table 4.16). In case of interaction between cultivars and storage temperature, the maximum reducing sugars content (6.99 %) was recorded in C_2 T_1 (Redlum Gala + 0°C) and minimum reducing sugars content (5.13 %) was recorded in C_1 T_3 (Jeromine + Room Temperature). Among the interaction between cultivars and storage duration the highest reducing sugars content increased with increase in storage duration up to 45 days. However, after 45 days of storage, the highest reducing sugar content (7.71 %) was recorded in cultivar Redlum Gala (C_2D_4) and lowest reducing sugars content (6.77 %) was observed in Jeromine cultivar (C_1 D_4).

Considering the interaction between storage temperature and storage duration, the reducing sugars content variably increased with respect to increase in storage duration and different temperatures. After 45 days of storage, the highest reducing sugars content (8.18 %) was observed in T_1 D_4 (0°C + 45 days) and lowest in T_3 D_4 (Room Temperature + 45 days) having reducing sugars content of 6.52 per cent.

Among three factor interactions between cultivars, storage duration and storage temperatures, exhibited a significant effect on fruit reducing sugars content during storage. The reducing sugars content increased with increasing storage duration with respect of storage temperature and cultivars. After 45 days of storage, the highest reducing sugars content (9.12 %) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days) having reducing sugar content of 6.06 per cent.

Table 4.16 Effect of different cultivars, storage duration and temperatures on reducing sugars content of apple during storage

C / T / D	Reducing Sugars (%)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	3.54	3.47	3.58	**3.54**	4.09	4.04	4.06	**4.07**
D_2(15 days)	5.14	5.07	4.98	**5.06**	6.47	5.96	5.81	**6.07**
D_3(30 days)	6.09	5.94	5.89	**5.97**	8.27	6.78	6.42	**7.16**
D_4(45 days)	7.25	7.01	6.06	**6.77**	9.12	7.02	6.98	**7.71**
Mean(C×T)	**5.51**	**5.37**	**5.13**		**6.99**	**5.95**	**5.82**	
	Mean (C_1) 5.34				**Mean (C_2) 6.25**			

T / D	T × D			Mean (D)
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	
D_1 (0 day)	3.82	3.76	3.82	**3.81**
D_2(15 days)	5.81	5.52	5.39	**5.57**
D_3(30 days)	7.18	6.36	6.16	**6.57**
D_4(45 days)	8.18	7.02	6.52	**7.24**
Mean(T)	**6.25**	**5.66**	**5.47**	

$CD_{0.05}$	
C	0.02
T	0.02
D	0.03
C×T	0.03
C×D	0.03
T×D	0.04
C×T×D	0.06

C- Cultivars; T- Storage Temperatures; D – Storage Duration

4.2.10 Non-reducing sugars

The perusal of data presented in Table 4.17 revealed that different cultivars, storage temperatures and storage duration exhibited a significant effect on non-reducing sugars content in apple during storage. Among the cultivars, the highest non-reducing sugars content (2.04 %) was observed in C_2 (Redlum Gala) and the lower non-reducing sugars content (1.74

%) was observed in C_1 (Jeromine). In case of storage temperatures, the highest non-reducing sugars content (2.08 %) was recorded in T_1 (0°C) and the lowest non-reducing sugars content (1.66 %) was recorded in T_3 (Room Temperature). With respect to different storage duration, the non-reducing sugars content showed decreasing trend. The maximum non-reducing sugars content (2.23 %) was observed in D_1 (0 day) and the minimum non-reducing sugars content (1.38 %) was observed in D_3 (30 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on reducing sugar content (Table 4.17). In case of interaction between cultivars and storage temperature, the maximum non-reducing sugars content (2.26 %) was recorded in C_2 T_2 (Redlum Gala + 4°C) which was statistically at par with C_2 T_1 (Redlum Gala + 0°C) and minimum non-reducing sugars content (1.62 %) was recorded in C_1 T_2 (Jeromine + 4°C). Among the interaction between cultivars and storage duration, the highest non-reducing sugars content (2.39 %) was recorded in Redlum Gala cultivar stored for 45 days (C_2 D_4), and lowest non-reducing sugars content (1.24 %) was observed in Jeromine cultivar stored for 30 days (C_1 D_3). Considering the interaction between storage temperature and storage duration, the significantly highest non-reducing sugars content (2.36 %) was observed in T_1 D_2 (0°C + 15 days) and lowest in T_3 D_3 (Room Temperature + 30 days) having non-reducing sugars content of 1.21 per cent.

Among three factor interactions, between cultivars, storage duration and storage temperatures, the highest non-reducing sugars content (3.57 %) was recorded in C_2 T_2 D_4 (Redlum Gala + 4°C + 45 days) and lowest in C_1 T_2 D_4 (Jeromine + 4°C + 45 days) having non-reducing sugars content of 0.93 per cent.

The TSS, sugars content and acidity varied with respect to cultivars, storage duration and temperature during the course of study. Redlum Gala recorded highest TSS and sugars content with respect to different storage duration and temperatures in comparison to Jeromine. The variation among cultivars in TSS and sugar content is mainly due to genetical characters (Singh *et al*., 2003). Similar results were attained by Semwal (2020), who also recorded highest TSS and sugars content in Redlum Gala cultivar in comparison to all other cultivars evaluated under high density plantation in mid-hills of Himachal Pradesh at UHF Nauni Solan. The TSS and sugars content gradually increases with the storage duration up to a certain extent, then decreased. The increase in TSS might be associated with transformation

of pectin substance, starch, hemi-cellulose and other polysaccharides into soluble sugars as well as dehydration of fruits (Bhullar *et al*., 1981). The increase in sugar during storage may possible due to breakdown of complex organic metabolites into simple molecules or due to hydrolysis of starch into sugars. However, after an extent when complete hydrolysis of starch is done, no further increase in sugars content occurs and there is subsequent decline, as they along with organic acid are primary substrate for respiration (Wills *et al*.,1980), this would have lead to decrease in sugars content after 30 days of storage in apple fruits. The present finding is also in accordance with those of Kishor *et al*., (2018) who also reported similar trend of TSS and sugars content in different apple cultivars during storage. Pandey *et al*. (2006) also recorded sharp increased level of TSS and sugars content in apple cultivars stored under ambient conditions. The titratable acidity consistently decreased with respect to storage duration and cultivars. The decline in titratable acidity during storage in both cultivars may be associated with conversion of organic acids to sugars. Similar pattern in change of titratable acidity level in apple cultivars during storage was reported by Singh *et al*. (2007); Ghafir *et al*. (2009); Sharma *et al*. (2009) and Kishor *et al*. (2018). Further, low temperature storage also accounted for lower loss of TSS, sugars and acidity content with respect to storage period in comparison to storage at 4°C and room temperature.

Table 4.17 Effect of different cultivars, storage duration and temperatures on non-reducing sugars content of apple during storage

C / T / D	Non-Reducing Sugars (%)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	2.21	2.35	2.16	**2.24**	2.19	2.26	2.20	**2.22**
D_2(15 days)	1.96	1.93	1.87	**1.92**	2.76	1.74	1.67	**2.06**
D_3(30 days)	1.31	1.29	1.12	**1.24**	1.76	1.48	1.30	**1.51**
D_4(45 days)	2.20	0.93	1.60	**1.58**	2.27	3.57	1.34	**2.39**
Mean(C×T)	**1.92**	**1.62**	**1.69**		**2.24**	**2.26**	**1.63**	
	Mean (C_1) 1.74				**Mean (C_2) 2.04**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	2.20	2.30	2.18	**2.23**	C	0.02
D_2(15 days)	2.36	1.84	1.77	**1.99**	T	0.02
D_3(30 days)	1.54	1.38	1.21	**1.38**	D	0.03
D_4(45 days)	2.24	2.25	1.47	**1.98**	C×T	0.04
Mean(T)	**2.08**	**1.94**	**1.66**		C×D	0.04
					T×D	0.05
					C×T×D	0.07

C-cultivars; T- Storage Temperatures; D- Storage duration

Similar results were also obtained by Farooq *et al*. (2012), who also showed highest TSS, sugars content and acidity in apple fruits cv. Gala Must stored at room temperature. Lu *et al*. (2021) also recorded highest TSS and acidity content in apple cv. Meihong stored at low temperature (0 ± 5°C) in comparison to fruits stored at room temperature.

4.2.11 Ascorbic acid content

The data on the effect of different cultivars, storage temperatures, storage time and their interactions on ascorbic acid content recorded during 2022 is depicted in 4.18. The perusal of data presented in Table 4.18 revealed that the different cultivars, storage temperatures and storage time exhibited significant effect on ascorbic acid content in apple during storage. Among the cultivars, the highest ascorbic acid content (3.36 mg/100g) was observed in C_1 (Jeromine) and the lowest ascorbic acid content (3.17 mg/100g) was observed in C_2 (Redlum Gala).

In case of storage temperatures, the highest ascorbic acid content (3.63 mg/100g) was recorded in T_1 (0°C). However, the lowest ascorbic acid content (2.97 mg/100g) was recorded in T_3 (Room Temperature). Among different storage time the ascorbic acid showed decreasing trend with respect to increase in storage time. The maximum ascorbic acid content (4.63 mg/100g) was observed in D_1 (0 day) and the minimum ascorbic acid content (2.25 mg/100g) was observed in D_4 (45 days). The interaction effect of cultivars and storage temperature, cultivars and storage time, storage temperature and storage time, and cultivars, storage temperature and storage time were significant on ascorbic acid content (Table 4.18). In case of interaction between cultivars and storage temperature, the maximum ascorbic acid content (3.76 mg/100g) was recorded in treatment combination C_1 T_1 (Jeromine + 0°C) and minimum ascorbic acid content (2.88 mg/100g) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage time, the highest ascorbic acid content (4.71 mg/100g) was recorded in Jeromine cultivar stored at 0 days, which further decreased with increase in storage time for 45 days. After 45 days of storage the highest ascorbic acid content (2.40 mg/100g) was recorded in cultivar Jeromine (C_1D_4) and lowest ascorbic acid content (2.09 mg/100g) was recorded in Redlum Gala cultivar stored for 45 days (C_2 D_4). Considering the interaction between storage temperature and storage time, the significantly highest ascorbic acid content (4.64 mg/100g) was observed in T_1 D_1 (0°C + 0 day) and T_3 D_1 (Room Temperature + 0 day) which was statistically at par with T_2 D_1 (0°C +

0 day). Ascorbic acid variably decreased with respect to increase in storage time and different temperatures. After 45 days of storage, the highest ascorbic acid content (2.82 mg/100g) was observed in T_1 D_4 (0°C + 45 days) and lowest was found T_3 D_4 (Room Temperature + 45 days) having ascorbic acid content of 1.72 mg/100g.

Among three factor interactions, the highest ascorbic acid content (4.89 mg/100g) was recorded in C_1 T_3 D_1 (Jeromine + 0°C + 0 day) which was statistically at par with C_1 T_2 D_1 (Jeromine + 4°C + 0 day). Further the ascorbic acid showed decreasing trend with increasing storage time and with respect of storage temperature and cultivars. The highest ascorbic acid content (3.13 mg/100g) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest ascorbic acid content (1.57 mg/100g) in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

Table 4.18 Effect of different cultivars, storage duration and temperatures on ascorbic acid content of apple during storage

C / T / D	Ascorbic acid content (mg/100g)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	4.39	4.85	4.89	**4.71**	4.89	4.37	4.39	**4.55**
D_2(15 days)	4.07	3.45	3.35	**3.62**	3.76	3.40	3.13	**3.43**
D_3(30 days)	3.45	2.55	2.12	**2.70**	2.82	2.51	2.43	**2.59**
D_4(45 days)	3.13	2.19	1.88	**2.40**	2.51	2.19	1.57	**2.09**
Mean(C×T)	**3.76**	**3.26**	**3.06**		3.50	3.12	2.88	
	Mean (C_1) 3.36				**Mean (C_2) 3.17**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	**T_2 (4°C)**	**T_3 (Room Temperature)**		C	0.01		
D_1 (0 day)	4.64	4.61	4.64	**4.63**	T	0.02		
D_2(15 days)	3.92	3.43	3.24	**3.53**	D	0.02		
D_3(30 days)	3.13	2.53	2.28	**2.65**	C×T	0.02		
D_4(45 days)	2.82	2.19	1.72	**2.25**	C×D	0.03		
Mean(T)	**3.63**	**3.19**	**2.97**		T×D	0.03		
					C×T×D	0.05		

C- Cultivars; T – Storage Temperatures; D – Storage duration

4.2.12 Anthocyanin content (A_{530} - OD)

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on fruit weight recorded during 2022 is presented in Table 4.19. It is inferred from the data that cultivars, storage temperatures and storage duration and their interactions had significant effect on anthocyanin content.

The data depicted in Table 4.19 revealed that different cultivars, storage temperatures and storage duration exhibited significant effect on anthocyanin content. Among the cultivars, the maximum anthocyanin content (1.43 A_{530}-OD) was observed in C_1 (Jeromine) and the lowest anthocyanin content (1.25 A_{530}-OD) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest anthocyanin content (1.45 A_{530}-OD) was recorded in T_1 (0°C) and the lowest anthocyanin content (1.23 A_{530}-OD) was recorded in T_3 (Room temperature). With respect to different storage duration, the anthocyanin content showed decreasing trend with respect to prolonging storage period. The maximum anthocyanin content (1.84 A_{530}-OD) was observed in D_1 (0 day) and the minimum anthocyanin content (0.95 A_{530}-OD) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant on anthocyanin content (Table 4.19). In case of interaction between cultivars and storage temperature, the maximum anthocyanin content (1.56 A_{530}-OD) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum anthocyanin content (1.16 A_{530}-OD) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage duration the highest anthocyanin content (2.01 A_{530}-OD) was recorded in Jeromine cultivar stored at 0 days, which further decreased with increase in storage duration for 45 days. After 45 days of storage, the highest anthocyanin content (1.00 A_{530}-OD) was recorded in cultivar Jeromine (C_1 D_4) and lowest anthocyanin content (0.90 A_{530}-OD) was observed in Redlum Gala cultivar (C_2 D_4). Considering the interaction between storage temperature and storage duration, the significantly highest anthocyanin content (1.86 A_{530}-OD) was observed in T_3 D_1 (Room Temperature + 0 day) which was statistically at par with T_3 D_1 (0°C + 0 day) and T_2 D_1 (4°C + 0 day). Further the anthocyanin content variably decreased with respect to increase in storage duration and different temperatures. After 45 days of storage, the highest anthocyanin content (1.10 A_{530}-OD) was observed in T_1 D_4 (0°C + 45 days) and lowest in T_3 D_4 (Room Temperature + 45 days) having anthocyanin content of 0.83 A_{530}-OD.

Among three factor interactions, the highest anthocyanin content (2.02 A_{530}-OD) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 45 days) and C_1 T_3 D_1 (Redlum Gala + Room Temperature + 0 day) which was statistically at par with C_1 T_2 D_1 (Jeromine + 4°C + 45 days). Further the anthocyanin content decreased with increasing storage duration with

respect of storage temperature and cultivars. The highest anthocyanin content (1.18 A_{530}-OD) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest anthocyanin content (0.82 A_{530}-OD) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days) which was statistically at par with C_2 T_2 D_4 (Redlum Gala + 4°C + 45 days).

Table 4.19 Effect of different cultivars, storage duration and temperatures on anthocyanin content of apple during storage

C / T / D	Anthocyanin content (A_{530}-OD)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	2.02	1.98	2.02	**2.01**	1.68	1.65	1.69	**1.67**
D_2(15 days)	1.75	1.69	1.23	**1.56**	1.42	1.33	1.23	**1.33**
D_3(30 days)	1.29	1.17	1.05	**1.17**	1.24	1.12	0.91	**1.09**
D_4(45 days)	1.18	0.98	0.85	**1.00**	1.03	0.86	0.82	**0.90**
Mean(C×T)	**1.56**	**1.46**	**1.29**		**1.34**	**1.24**	**1.16**	
	Mean (C_1) 1.43				**Mean (C_2) 1.25**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	1.85	1.81	1.86	**1.84**	C	0.02
D_2(15 days)	1.58	1.51	1.23	**1.44**	T	0.03
D_3(30 days)	1.27	1.15	0.98	**1.13**	D	0.04
D_4(45 days)	1.10	0.92	0.83	**0.95**	C×T	0.03
Mean(T)	**1.45**	**1.35**	**1.23**		C×D	0.05
					T×D	0.06
					C×T×D	0.08

C- Cultivars; T – Storage Temperatures; D – Storage duration

4.2.13 Total phenols

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on total phenols recorded during 2022 is depicted in Table 4.20. The data presented in Table 4.20 revealed that different cultivars, storage temperatures and storage duration exhibited significant effect on total phenols content. Among the cultivars, the maximum total phenols content (501.79 mg GAE/100 g) was observed in C_1 (Jeromine) and the minimum total phenols content (408.16 mg GAE/100 g) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest total phenols content (462.06 mg GAE/100 g) was recorded in T_1 (0°C). However, the lowest total phenols content (448.84 mg GAE/100 g) was recorded in T_3 (Room temperature). With respect to different storage duration the total phenols showed decreasing trend with respect to prolonging storage period. The maximum total phenols content (499.29 mg GAE/100 g) was observed in D_1 (0 day) and the minimum total phenols content (407.18 mg GAE/100 g) was observed in D_4 (45 days).

The interaction effect of cultivars and storage duration, storage temperature and storage duration, and cultivars, storage temperature and storage duration were significant total phenols, however, the interaction between cultivars and storage temperature was found non- significant (Table 4.20). In case of interaction between cultivars and storage temperature, the maximum total phenols content (508.52 mg GAE/100 g) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum total phenols content (401.35 mg GAE/100 g) was recorded in C_2 T_3 (Redlum Gala + Room Temperature).

Among the interaction between cultivars and storage duration the highest total phenols content (534.31 mg GAE/100 g) was recorded in Jeromine cultivar stored at 0 days, which further decreased with increase in storage duration for 45 days. After 45 days of storage, the highest total phenols content (467.86 mg GAE/100 g) was recorded in cultivar Jeromine and lowest total phenols content (346.49 mg GAE/100 g) was observed in Redlum Gala cultivar. Considering the interaction between storage temperature and storage duration, the significantly highest total phenols content (499.79 mg GAE/100 g) was observed in T_3 D_1 (Room Temperature + 0 days) which was statistically at par with T_1 D_1 (0°C + 0 days) and T_2 D_1 (4°C + 0 days). Further the total phenols content variably decreases with respect to increase in storage duration and different temperatures. After 45 days of storage, the highest total phenols content (420.42 mg GAE/100 g) was observed in T_1 (0°C) and lowest in T_3 (Room Temperature) having total phenols content of 394.59 mg GAE/100 g.

Table 4.20 Effect of different cultivars, storage duration and temperatures on total phenols content of apple during storage

C / T / D	Total phenols (mg GAE/100g)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	534.31	530.98	537.64	**534.31**	463.60	467.27	461.94	**464.27**
D_2(15 days)	513.72	507.60	501.41	**507.58**	442.06	434.66	430.37	**435.70**
D_3(30 days)	505.22	495.75	491.30	**497.43**	396.71	382.93	378.90	**386.18**
D_4(45 days)	480.83	467.75	455.00	**467.86**	360.01	345.28	334.18	**346.49**
Mean(C×T)	**508.52**	**500.52**	**496.34**		**415.60**	**407.54**	**401.35**	
	Mean (C_1) 501.79				**Mean (C_2) 408.16**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	0.92		
D_1 (0 day)	498.96	499.12	499.79	**499.29**	T	1.13		
D_2(15 days)	477.89	471.13	465.89	**471.64**	D	NS		
D_3(30 days)	450.96	439.34	435.10	**441.80**	C×T	1.30		
D_4(45 days)	420.42	406.52	394.59	**407.18**	C×D	1.84		
Mean(T)	**462.06**	**454.03**	**448.84**		T×D	2.26		
					C×T×D	3.19		

C- Cultivars; T – Storage Temperatures; D – Storage duration

Among three factor interactions, the highest total phenols content (537.64 mg GAE/100 g) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). Further the total phenols decreased with increasing storage duration with respect of storage temperature and cultivars. After 45 days of storage, the highest total phenols content (480.83 mg GAE/100 g) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest total phenols content (334.18 mg GAE/100 g) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

4.2.14. Antioxidant activity

The data on the effect of different cultivars, storage temperatures, storage duration and their interactions on antioxidant activity recorded during 2022 is depicted in Table 4.21. It is inferred from the data that cultivars, storage temperatures and storage duration and their interactions had significant effect on antioxidant activity of apple during storage.

The perusal of data presented in Table 4.21 revealed that different cultivars, storage temperatures and storage duration exhibited significant effect on antioxidant activity. Among the cultivars, the highest antioxidant activity (86.87 %) was observed in C_1 (Jeromine) and the lowest antioxidant activity (86.59 %) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest antioxidant activity (88.28 %) was recorded in T_1 (0°C) and the lowest antioxidant activity (85.55 %) was recorded in T_3 (Room temperature). With respect to different storage duration the antioxidant activity showed decreasing trend with respect to prolonging storage period. The maximum antioxidant activity (89.68 %) was observed in D_1 (0 day) and the minimum antioxidant activity (83.70 %) was observed in D_4 (45 days).

The interaction effect of cultivars and storage temperature, cultivars and storage duration, storage temperature and storage time, and cultivars, storage temperature and storage duration were significant on antioxidant activity (Table 4.21). In case of interaction between cultivars and storage temperature, the maximum antioxidant activity (88.69 %) was recorded in C_1 T_1 (Jeromine + 0°C) and minimum antioxidant activity (85.35 %) was recorded in C_2 T_3 (Redlum Gala + Room Temperature). Among the interaction between cultivars and storage duration the highest antioxidant activity (89.93 %) was recorded in Jeromine cultivar stored at 0 days, which further decreased with increase in storage time for 45 days. After 45 days of storage, the highest antioxidant activity (83.73 %) was recorded in cultivar Jeromine (C_1 D_4) and lowest antioxidant activity (83.66 %) was recorded in Redlum Gala cultivar (C_2 D_4). Considering the interaction between storage temperature and storage time, the significantly

highest antioxidant activity (90.50 %) was observed in T_1 D_1 (0°C + 0 day). Further the antioxidant activity variably decreased with respect to increase in storage time and different temperatures. After 45 days of storage, the highest antioxidant activity (85.79 %) was observed in T_1 D_4 (0°C + 45 days) and lowest was found in T_3 D_4 (Room Temperature + 45 days) having antioxidant activity 81.22 per cent.

Among three factor interactions, the highest antioxidant activity (90.82 %) was recorded in C_1 T_3 D_1 (Jeromine + Room Temperature + 0 day) which was statistically at par with C_1 T_1 D_1 (Jeromine + 0°C + 0 day). Further the antioxidant activity decreased with increasing storage time with respect of storage temperature and cultivars. The highest antioxidant activity (86.31 %) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest antioxidant activity of (80.90 %) was observed in C_2 T_3 D_4 (Redlum Gala+ Room Temperature + 45 days).

The ascorbic acid content, anthocyanin, total phenols and antioxidant activity with respect to cultivars, storage duration and temperature varies significantly during storage. Jeromine recorded highest ascorbic acid content, anthocyanin, total phenols and antioxidant activity in comparison to Redlum Gala during storage. The different cultivars vary significantly in their ascorbic acid content and anthocyanin content (Nour *et al*., 2010). The results are in confirmatory with those of Jan and Rab (2012) who also reported highest ascorbic acid content in Red Delicious in comparison to Royal Gala, Mondial Gala and Golden Delicious. Semwal (2020) also reported highest ascorbic acid and anthocyanin content in Jeromine cultivar in comparison to Redlum Gala. The storage duration generally influences ascorbic acid in fruits, by decreasing their proportion with increasing storage duration (Hayat *et al*., 2003). This might be associated with differential ascorbic acid oxidase activity in fruits (Mapson, 1970). The results are in agreement with those of Ali *et al*., 2004, who also observed decreasing trend in ascorbic acid during storage of apple fruit at ambient room temperature. Jan and Rab (2012) also reported decline in ascorbic acid content of apple fruits with increase in storage duration. Similar results were also reported by Kishor *et al.,* (2018) who observed significantly decreasing trend in ascorbic acid as advancement of storage period in different apple cultivars.

The total phenols and antioxidant activity also varied significantly among cultivars, storage duration and temperatures during the course of study. The total phenols content significantly decreases with increase in storage duration. As with increase in storage period, the phenolic compounds in fruits are converted to α-quinones, therefore polymerized to

brown pigments resulting in decrease in level of total phenols content. There is linear correlation between antioxidant activity and total phenols as well as with anthocyanin content in fruit crops (Kalt *et al*., 1999; Wang and Lin 2000) which might be the reason for decrease in antioxidant activity during storage.

The Jeromine cultivar recorded highest ascorbic acid, anthocyanin, total phenols (Table 4.18, 4.19, 4.20, 4.21) which would have resulted highest antioxidant activity in their fruits in comparison to Redlum Gala. Similar results, were obtained by Lu *et al*. (2021) reported high level of antioxidant activity in 'Meihong' cultivars fruits during storage in comparison to "Golden Delicious" which may be related to substantial abundance of ascorbic acid, anthocyanin and other phenols in 'Meihong' cultivar. Further low temperature (0°C) significantly effect the total phenols and antioxidant activity of store apple in comparison to 4°C and room temperature. Low temperature storage minimizes the loss of TSS, TA and ascorbic acid from the fruit pulp and results in inhibition of degradation of phenolic compounds and further weakening of antioxidant activity (Tavarini *et al*., 2008). Hence in our present study, this reason might had led to better phenol content and antioxidant activity in those apple fruits which were stored under low temperature (0°C) in comparison to fruits stored at 4°C and room temperature.

Table 4.21 Effect of different cultivars, storage duration and temperatures on antioxidant activities of apple during storage

C / T / D	Antioxidant activity (%)							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	90.65	88.32	90.82	**89.93**	90.34	88.27	89.65	**89.42**
D_2(15 days)	89.98	87.97	86.17	**88.04**	88.03	87.86	86.02	**87.30**
D_3(30 days)	87.82	84.97	84.51	**85.77**	87.82	85.36	84.81	**85.99**
D_4(45 days)	86.31	83.35	81.54	**83.73**	85.26	84.81	80.90	**83.66**
Mean(C×T)	**88.69**	**86.15**	**85.76**		**87.86**	**86.57**	**85.35**	
	Mean (C_1) 86.87				**Mean (C_2) 86.59**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	0.05		
D_1 (0 day)	90.50	88.30	90.24	**89.68**	T	0.07		
D_2(15 days)	89.01	87.91	86.10	**87.67**	D	0.09		
D_3(30 days)	87.82	85.16	84.66	**85.88**	C×T	0.08		
D_4(45 days)	85.79	84.08	81.22	**83.70**	C×D	0.11		
Mean(T)	**88.28**	**86.36**	**85.55**		T×D	0.13		
					C×T×D	0.19		

C- cultivars; T – Storage Temperatures; D – Storage duration

The present findings are in accordance with those of Lu *et al*. (2021) who also maintained higher anthocyanin content, delay the decrease of total phenols content in apple cultivar 'Meihong' stored at low temperature (0°C) when compared to fruits stored at room temperature.

4.2.15. Sensory characteristics

4.2.15.1. Overall acceptability

The data on the effect of different cultivars, storage temperatures, storage time and their interactions on overall acceptability recorded during 2022 is depicted in Table 4.22. The perusal of data presented in Table 4.22 revealed that the different storage temperatures exerted a significant effect on fruit overall acceptability, however, different cultivars and storage time exhibited a non-significant effect on fruit overall acceptability. Among the storage temperatures, the highest overall acceptability score (8.00) was recorded in T_1 (0°C) which was statistically at par with T_2 (4°C) and the lowest overall acceptability score (6.84) was recorded in T_3 (Room Temperature).

Table 4.22. Effect of different cultivars, storage duration and temperatures on overall acceptability of apple during storage

C / T / D	Overall Acceptability							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	7.67	7.67	7.67	**7.67**	7.33	7.33	7.33	**7.33**
D_2(15 days)	8.67	8.57	7.00	**8.08**	8.00	7.67	7.00	**7.56**
D_3(30 days)	8.33	7.53	7.17	**7.68**	8.00	7.17	6.33	**7.17**
D_4(45 days)	8.00	6.80	6.00	**6.93**	8.00	7.10	6.20	**7.10**
Mean(C×T)	**8.17**	**7.64**	**6.96**		**7.83**	**7.32**	**6.72**	
	Mean (C_1) 7.59				**Mean (C_2) 7.29**			
T / D	**T × D**			**Mean (D)**	**$CD_{0.05}$**			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	NS		
D_1 (0 day)	7.50	7.50	7.50	**7.50**	T	0.51		
D_2(15 days)	8.33	8.12	7.00	**7.82**	D	NS		
D_3(30 days)	8.17	7.35	6.75	**7.42**	C×T	NS		
D_4(45 days)	8.00	6.95	6.10	**7.02**	C×D	NS		
Mean(T)	**8.00**	**7.48**	**6.84**		T×D	NS		
					C×T×D	NS		

C- Cultivars; T – Storage Temperatures; D – Storage duration

The percentage of the likeness of the apples indicated that in the early days of storage in both the apple cultivar were either liked extremely or moderately. The data indicated that panelists continued to like the apples extremely or moderately up to 15th day of storage. After

that, the percentage of overall acceptability decreased. The results obtained in the present investigation are found to be close conformity with the studies of Pandey *et al.* (2006), Issar *et al.* (2010) and Ahmad *et al*. (2021) in apple cultivars under storage.

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled **"Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"** was conducted in Department of Fruit Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, during the year 2022. The results obtained during the course of investigation have been summarized as under:

5.1 Effect of different precooling methods on the storability of apple cv. Jeromine

5.1.1 The highest fruit weight (107.35 g) was recorded in treatment P_3 (Hydro-cooling) and the lowest fruit weight (100.69 g) was observed in treatment P_1 (Control). With respect to storage days, maximum fruit weight (131.56 g) was observed in fruit stored for 0 days (D_1) and minimum fruit weight (80.08 g) was observed in fruits stored for 28 days (D_5). In case of interaction between precooling treatments and storage days the highest fruit weight (131.92 g) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days). But after 28 days of storage highest fruit weight (84.61 g) was recorded in P_3 D_5 (Hydro-cooling + 28 days) and lowest fruit weight (71.95 g) was recorded in P_1 D_5 (Control + 28 days).

5.1.2 The highest physiological loss in weight (23.04 %) was recorded in treatment P_1 (Control) and lowest physiological loss in weight (18.61 %) was recorded in P_3 (Hydro-cooling) With respect to storage days, the highest physiological loss in weight (39.13 %) was recorded in fruit stored for 28 days (D_5) and lowest in fruit stored for 0 day ($D_{1)}$. In case of interaction between precooling treatments and storage days, the fruits stored for 0 days in all precooling treatments resulted zero physiological loss in weight percentage but after 28 days of storage the highest physiological loss in weight (45.00 %) was recorded in treatment combination P_1 D_5 (Control + 28 days).

5.1.3 The highest fruit volume (121.80 cc) was recorded in treatment P_3 (Hydro-cooling) and the lowest fruit volume (114.07 cc) was observed in control (P_1). With respect to storage days, the maximum fruit volume (144.17 cc) was

observed in fruit stored for 0 days (D_1) and the minimum fruit volume (93.33 cc) was observed in fruits stored for 28 days (D_5). In case of interaction between precooling treatments and storage days, highest fruit volume (146.33 cc) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days). But after 28 days of storage, lowest fruit volume (83.00 cc) was observed in treatment combination P_1D_5 (Control + 28 days).

5.1.4 The highest fruit density (0.888 g/cc) was recorded in treatment P_2 (Field cooling) and the lowest fruit density (0.879 g/cc) was observed in treatments control (P_1). Regarding different storage days, the maximum fruit density (0.913 g/cc) was observed in fruit stored in 0 days (D_1) and the minimum fruit density (0.858 g/cc) was observed in fruits stored for 28 days (D_5). Among interaction between precooling treatments and storage days, the highest fruit density (0.920 g/cc) was recorded in treatment combination P_1 D_1 (Control + 0 days) and the lowest fruit density (0.833 g/cc) was recorded in P_4 D_5 (Air cooling + 28 days).

5.1.5 The highest fruit firmness (4.60 kg/cm^2) was recorded in treatment P_3 (Hydro-cooling) and the lowest fruit firmness (4.18 kg/cm^2) was observed in control (P_1). With respect to storage days the maximum fruit firmness (8.66 kg/cm^2) was observed in fruit stored in 0 days (D_1) and the minimum fruit firmness (2.18 kg/cm^2) was observed in fruits stored for 28 days (D_5). In case of interaction between precooling treatments and storage days, the highest fruit firmness (8.78 kg/cm^2) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days) and lowest fruit firmness (1.87 kg/cm^2) was recorded in P_1 D_5 (Control + 28 days).

5.1.6 The maximum TSS content (11.48°B) was recorded in treatment P_3 (Hydro-cooling) and the minimum TSS content (11.27°B) was observed in control (P_1). Regarding different storage days, maximum TSS content (12.63°B) was observed in fruit stored for 21 days (D_4) and minimum TSS content (9.62 °B) was observed in fruits stored for 0 days (D_1). In case of interaction between precooling treatments and storage days, the maximum fruit TSS content (13.54°B) was recorded in P_3 D_5 (Hydro-cooling + 28 days) and the minimum TSS content (9.43°B) was recorded in P_3 D_1 (Hydro-cooling + 0 days).

5.1.7 The highest titratable acidity (0.19 %) was recorded in treatment P_3 (Hydro-cooling) and the lowest titratable acidity (0.16 %) was observed in control (P_1). With respect to different storage days, the maximum titratable acidity (0.22 %)

was observed in fruit stored in 0 days (D_1) and minimum titratable acidity (0.15 %) was observed in fruits stored for 28 days (D_5). Among interaction between precooling treatments and storage days, highest titratable acidity (0.24 %) was recorded in treatment combination P_3 D_1 (Hydro- cooling + 0 days) and the lowest titratable acidity (0.14 %) was recorded in P_1 D_5 (Control + 28 days).

5.1.8 The highest total sugars content (7.96 %) was recorded in treatment P_3 (Hydro-cooling) and the lowest total sugars content (5.78 %) was observed in treatment P_1 (control). With respect to storage days, the maximum total sugars content (8.27 %) was observed in fruit stored for 21 days (D_4) and the minimum total sugars content (6.38 %) was observed in fruits stored for 0 days (D_1). Regarding interaction between precooling treatments and storage days, the highest total sugars content (9.85 %) was recorded in treatment combination P_3 D_4 (Hydro-cooling + 21 days) and the lowest total sugars content (4.96 %) was recorded in P_3D_1 (Hydro-cooling + 0 days), which was statistically at par with P_4 D_1 (Air-Cooling + 0 days).

5.1.9 The highest reducing sugars content (4.37 %) was recorded in treatment P_3 (Hydro-cooling) and the lowest reducing sugars content (3.03%) was observed in control (P_1). With respect to storage days, the maximum reducing sugars content (4.28 %) was observed in fruit stored in 21 days (D_4) and the minimum reducing sugars content (3.57 %) was observed in fruits stored for 0 days (D_1). Among interaction between precooling treatments and storage days, the highest reducing sugars content (5.11 %) was recorded in treatment combination P_3 D_4 (Hydro- cooling + 21 days) and the lowest reducing sugars content (2.26 %) was recorded in P_3D_1 (Hydro-cooling + 0 days).

5.1.10 The highest non-reducing sugars content (3.41 %) was recorded in treatment P_3 (Hydro-cooling) and the lowest non-reducing sugars content (2.62 %) was observed in treatment P_1 (Control). With respect to different storage days, the maximum non-reducing sugars content (3.79 %) was observed in fruit stored for 21 days (D_4) and the minimum non-reducing sugars content (2.67 %) was observed in fruits stored at 0 days (D_1).Among the interaction between precooling treatments and storage days, the highest non-reducing sugars content (4.50 %) was recorded in treatment combination of P_3 D_4 (Hydro-cooling + 21 days), and the lowest non-reducing sugars content (2.38 %) was recorded in P_3 D_1 (Hydro-cooling + 0 days).

5.1.11 The highest ascorbic acid content (3.51 mg/100g) was recorded in treatment P_3 (Hydro-cooling) and the lowest ascorbic acid content (2.47 mg/100g) was observed in control (P_1). With respect to different storage days, the maximum ascorbic acid (4.44 mg/100g) was observed in fruit stored in 0 days (D_1), and the minimum ascorbic acid content (1.80 mg/100g) was observed in fruits stored for 28 days (D_5). Among the interaction between precooling treatments and storage days, the highest ascorbic acid content (4.51 mg/100g) was recorded in treatment combination P_1 D_1 (Control + 0 days) and lowest ascorbic acid content (1.25 mg/100g) after 28 days of storage in P_1 D_5 (Control + 28 days).

5.1.12 The highest anthocyanin content (1.19 A_{530}-OD) was recorded in treatment P_3 (Hydro-cooling) and the lowest anthocyanin content (0.98 A_{530}-OD) was observed in control (P_1). With respect to storage days, the maximum anthocyanin content (1.36 A_{530}-OD) was observed in fruit stored in 0 days (D_1) and the minimum anthocyanin content (0.87 A_{530}-OD) was observed in fruits stored for 28 days (D_5). In case of interaction between different precooling treatments and storage days, highest anthocyanin content (1.39 A_{530}-OD) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days) and the lowest anthocyanin content (0.70 A_{530}-OD) was recorded in P_1 D_5 (Control + 28 days).

5.1.13 The highest total phenols content (475.82 mg GAE/100g) was recorded in treatment P_3 (Hydro-cooling) and the lowest total phenols content (468.69 mg GAE/100g) was observed in Control (P_1). Regarding storage days, the maximum total phenols (540.37 mg GAE/100g) was observed in fruit stored in 0 days (D_1) and the minimum total phenols content (413.29 mg GAE/100g) was observed in fruits stored for 28 days (D_5). In case of the interaction between precooling treatments and storage days, highest total phenols content (541.02 mg GAE/100g) was recorded in treatment combination P_3 D_1 (Hydro-cooling + 0 days) and the lowest total phenols (405.43 mg GAE/100g) was recorded in P_1 D_5 (Control + 28 days).

5.1.14 The highest antioxidant activity (85.39 %) was recorded in treatment P_3 (Hydro-cooling) and the lowest antioxidant activity (80.98 %) was observed in Control (P_1). With respect to storage days, the maximum antioxidant activity (86.95 %) was observed in fruit stored in 0 days (D_1), the minimum antioxidant activity

(78.30 %) was observed in fruits stored for 28 days (D_5). In case of interaction between precooling treatments and storage days the highest antioxidant activity (87.97 %) was recorded in treatment combination P_3 D_1 (Hydro- cooling + 0 days) and the lowest antioxidant activity (73.88 %) was recorded in P_1 D_5 (Control + 28 days).

5.2 Studies on the storability of exotic cultivars of apple under different storage conditions

5.2.1 Among the cultivars, the highest fruit weight (109.22 g) was observed in C_1 (Jeromine) and the lower fruit weight (86.88 g) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest fruit weight (102.41 g) was recorded in T_1 (0°C) and the lowest fruit weight (93.65 g) was recorded in T_3 (Room temperature). With respect to different storage time, the maximum fruit weight (114.68 g) was observed in D_1 (0 day) and the minimum fruit weight (84.34 g) was observed in D_4 (45 days). Among three factor interactions, the highest fruit weight (126.09 g) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). But after 45 days of storage, the highest fruit weight (104.00 g) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest fruit weight (66.16 g) was recorded in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.2 Among the cultivars, the higher physiological loss in weight (16.49 %) was observed in C_2 (Redlum Gala) and the lower physiological loss in weight (12.84 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest physiological loss in weight (18.76 %) was recorded in T_3 (Room Temperature) and the lowest physiological loss in weight (11.13 %) was recorded in T_1 (0°C). Regarding the storage time, no physiological loss in weight was observed in D_1 (0 days), however, after 45 days (D_4) of storage recorded maximum physiological loss in weight (26.67 %). Among three factor interactions, no physiological loss in weight was recorded in 0 days (D_1) with respect of both the cultivars and all storage temperatures. But after 45 days of storage, the highest physiological loss in weight (37.04 %) was recorded in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days) and the lowest physiological loss in weight (17.52 %) was recorded in treatment combination C_1 T_1 D_4 (Jeromine + 0°C + 45 days).

5.2.3 Among the cultivars, the maximum fruit volume (121.54 cc) was observed in C_1 (Jeromine) and the lowest fruit volume (98.72 cc) was observed in C_2 (Redlum Gala). Regarding storage temperatures, the highest fruit volume (115.28 cc) was recorded in T_1 (0°C) and the lowest fruit volume (104.75 cc) was recorded in T_3 (Room temperature). With respect to different storage time, the maximum fruit volume (130.62 cc) was observed in D_1 (0 day) and the minimum fruit volume (93.67 cc) was observed in D_4 (45 days). Among three factor interactions, the highest fruit volume (144.91 cc) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). But after 45 days of storage, the highest fruit volume (113.33 cc) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest fruit volume (76.33 cc) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.4 The higher fruit density (0.902 g/cc) was observed in C_1 (Jeromine) and lowest fruit density (0.880 g/cc) was observed in C_2 (Redlum Gala). Among different storage time, the highest fruit density (0.899 g/cc) was recorded in D_4 (45 days) and lowest fruit density (0.878 g/cc) was recorded in D_1 (Room temperature (20-22°C). In case of three factor interactions, the highest fruit density (0.939 g/cc) was recorded in C_1 T_3 D_3 (Jeromine + Room Temperature (20-22°C) + 30 days) and lowest fruit density (0.850 g/cc) was recorded in C_2 T_2 D_3 (Redlum Gala + 4°C + 30 day).

5.2.5 Among the cultivars, the highest fruit firmness (6.41 kg/cm^2) was observed in C_1 (Jeromine) and the lowest fruit firmness (5.22 kg/cm^2) was observed in C_2 (Redlum Gala). Regarding storage temperatures, the highest fruit firmness (6.77 kg/cm^2) was recorded in T_1 (0°C) and the lowest fruit firmness (4.43 kg/cm^2) was recorded in T_3 (Room temperature). Among the storage time, the maximum fruit firmness (7.89 kg/cm^2) was observed in D_1 (0 day) and the minimum fruit firmness (4.14 kg/cm^2) was observed in D_4 (45 days). In case of three factor interactions, the highest fruit firmness (8.75 kg/cm^2) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). After 45 days of storage, the highest fruit firmness (6.07 kg/cm^2) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest fruit firmness (1.98 kg/cm^2) was recorded in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.6 Among the cultivars, the highest total soluble solids content (13.21 °B) was observed in C_2 (Redlum Gala) and the lowest total soluble content (11.12 °B) was observed in C_1 (Jeromine). In case of storage temperatures, the highest total

soluble content (12.42 °B) was recorded in T_1 (0°C) and lowest total soluble solids content (11.91 °B) was recorded in T_3 (Room temperature). Among the storage time the maximum total soluble solids content (13.39 °B) was observed in D_3 (30 days) and the minimum total soluble solids content (10.16 °B) was observed in D_1 (0 day). Among three factor interaction between cultivars, storage time and temperatures the highest total soluble solids content (15.80 °B) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest total soluble solids content (11.07 °B) was recorded in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days).

5.2.7 Regarding cultivars, highest titratable acidity (0.32 %) was recorded in Jeromine (C_1) and lowest titratable acidity (0.19 %) was found in Redlum Gala (C_1). With respect to storage temperatures, the highest titratable acidity (0.27 %) was recorded in T_1 (0°) and lowest titratable acidity (0.24 %) in T_3 (Room Temperature). Among different storage time, the maximum titratable acidity (0.35 %) was observed in D_1 (0 day) and the minimum titratable acidity (0.19 %) was observed in D_4 (45 days). Among three factor interactions, the highest titratable acidity (0.48 %) was recorded in C_1 T_2 D_1 (Jeromine + 4°C + 0 day). After 45 days of storage, the highest titratable acidity (0.24 %) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest titratable acidity (0.13 %) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature (20-22°C) + 45 days).

5.2.8 Among the cultivars, the higher total sugars content (8.41 %) was observed in C_2 (Redlum Gala) and the lower total sugars content (7.17 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest total sugars content (8.44 %) was recorded in T_1 (0°C) and the lowest total sugars content (7.22 %) was recorded in T_3 (Room Temperature). With respect to different storage time, the minimum total sugar content (6.15 %) was observed in D_1 (0 day) and the maximum total sugar content (9.33 %) was observed in D_4 (45 days). Among three factor interactions, after 45 days of storage, the highest total sugars content (11.51 %) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest total sugars content (7.73 %) was recorded in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days).

5.2.9 Among the cultivars, the higher reducing sugars content (6.25 %) was observed in C_2 (Redlum Gala) and the lowest reducing sugars content (5.34 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest reducing

sugar content (6.25 %) was recorded in T_1 (0°C) and the lowest reducing sugars content (5.47 %) was recorded in T_3 (Room temperature). With respect to different storage time, the minimum reducing sugars content (3.81 %) was observed in D_1 (0 day) and the maximum reducing sugars content (7.24 %) was observed in D_4 (45 days). In case of three factor interaction, after 45 days of storage, the highest reducing sugars content (9.12 %) was recorded in C_2 T_1 D_4 (Redlum Gala + 0°C + 45 days) and lowest in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days) having reducing sugar content of 6.06 per cent.

5.2.10 Among the cultivars, the highest non-reducing sugars content (2.04 %) was observed in C_2 (Redlum Gala) and the lower non-reducing sugars content (1.74 %) was observed in C_1 (Jeromine). In case of storage temperatures, the highest non-reducing sugar content (2.08 %) was recorded in T_1 (0°C) and the lowest non-reducing sugars content (1.66 %) was recorded in T_3 (Room temperature). With respect to different storage time, the maximum non-reducing sugars content (2.23 %) was observed in D_1 (0 day) and the minimum non-reducing sugars content (1.38 %) was observed in D_3 (30 days). Among three factor interactions, the highest non-reducing sugars content (3.57 %) was recorded in C_2 T_2 D_4 (Redlum Gala + 4°C + 45 days) and lowest non-reducing sugars content (0.93 %) was observed in C_1 T_2 D_4 (Jeromine + 4°C + 45 days).

5.2.11 Among the cultivars, the highest ascorbic acid content (3.36 mg/100g) was observed in C1 (Jeromine) and the lowest ascorbic acid content (3.17 mg/100g) was observed in C2 (Redlum Gala). In case of storage temperatures, the highest ascorbic acid content (3.63 mg/100g) was recorded in T1 (0°C). However, the lowest ascorbic acid content (2.97 mg/100g) was recorded in T3 (Room temperature). Among different storage time the ascorbic acid showed decreasing trend with respect to increase in storage time. The maximum ascorbic acid content (4.63 mg/100g) was observed in D1 (0 day) and the minimum ascorbic acid content (2.25 mg/100g) was observed in D4 (45 days). Among three factor interactions, the highest ascorbic acid content (4.89 mg/100g) was recorded in C_1 T_3 D_1 (Jeromine + 0°C + 0 day). Further the ascorbic acid showed decreasing trend with increasing storage time and with respect of storage temperature and cultivars. The highest ascorbic acid content (3.13 mg/100g) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine +

0°C + 45 days) and lowest ascorbic acid content (1.57 mg/100g) in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.12 Among the cultivars, the maximum anthocyanin content (1.43 A_{530} OD) was observed in C_1 (Jeromine) and the lowest anthocyanin content (1.25 A_{530} OD) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest anthocyanin content (1.45 A_{530} OD) was recorded in T_1 (0°C) and the lowest anthocyanin content (1.23 A_{530} OD) was recorded in T_3 (Room temperature). With respect to different storage time, the maximum anthocyanin content (1.84 A_{530} OD) was observed in D_1 (0 day) and the minimum anthocyanin content (0.95 A_{530} OD) was observed in D_4 (45 days). Among three factor interactions, the highest anthocyanin content (2.02 A_{530} OD) was recorded in C_1 T_3 D_1 (Redlum Gala + Room Temperature + 0 day). After 45 days of storage, the highest anthocyanin content (1.18 A_{530} OD) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest anthocyanin content (0.82 A_{530} OD) was observed in C_1 T_3 D_4 (Jeromine + Room Temperature + 45 days).

5.2.13 Among the cultivars, the maximum total phenols content (501.79 mg/100g) was observed in C_1 (Jeromine) and the minimum total phenols content (408.16 mg/100g) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest total phenols content (462.06 mg/100g) was recorded in T_1 (0°C). However, the lowest total phenols content (448.84 mg/100g) was recorded in T_3 (Room temperature). With respect to different storage time, the maximum total phenols content (499.29 mg/100g) was observed in D_1 (0 day) and the minimum total phenols content (407.18 mg/100g) was observed in D_4 (45 days). Among three factor interactions, the highest total phenols content (537.64 mg/100g) was recorded in C_1 T_1 D_1 (Jeromine + 0°C + 0 day). After 45 days of storage, the highest total phenols content (480.83 mg/100g) was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest total phenols content (334.18 mg/100g) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.14 Among the cultivars, the highest antioxidant activity (86.87 %) was observed in C_1 (Jeromine) and the lowest antioxidant activity (86.59 %) was observed in C_2 (Redlum Gala). In case of storage temperatures, the highest antioxidant activity (88.28 %) was recorded in T1 (0°C) and the lowest antioxidant activity (85.55 %) was recorded in T_3 (Room Temperature). With respect to different storage time, the maximum antioxidant activity (89.68 %) was observed in D_1 (0 day)

and the minimum antioxidant activity (83.70 %) was observed in D_4 (45 days). Among three factor interactions, the highest antioxidant activity (90.82 %) was recorded in C_1 T_3 D_1 (Jeromine + Room Temperature + 0 day). Further the antioxidant activity decreased with increasing storage time with respect of storage temperature and cultivars. The highest antioxidant activity (86.31 %) after 45 days of storage was recorded in C_1 T_1 D_4 (Jeromine + 0°C + 45 days) and lowest antioxidant activity of (80.90 %) was observed in C_2 T_3 D_4 (Redlum Gala + Room Temperature + 45 days).

5.2.15 The different storage temperatures exerted a significant effect on fruit overall acceptability, however, different cultivars and storage time exhibited a non-significant effect on fruit overall acceptability. Among the storage temperatures, the highest overall acceptability score (8.00) was recorded in T_1 (0°C) and the lowest overall acceptability score (6.84) was recorded in T_3 (Room temperature).

CONCLUSION

- From the present investigation it can be concluded that the hydro-cooling was found to be the best precooling treatment for apple, significantly followed by air cooling accounting for minimum physiological loss in weight and retention of better firmness during storage.
- The fruit quality was significantly affected by cultivars and storage conditions, however, the fruits of Jeromine cultivar when stored at 0°C retained better shelf-life and fruit quality attributes in comparison to Redlum Gala.

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APPENDIX-I

SENSORY SCORE CARD FOR APPLE ON 9-POINT HEDONIC SCALE

Product: Apple cv. Jeromine/Redlum Gala during storage (0-45 days)

Method: 9-Point Hedonic Rating Test (According to BIS IS: 6273 (Part II)-1971)

Name of the Panelist: Designation:

Dated:

Sample No.	Storage Period (Days)	Temperature (˚C)	Colour/ Appearance	Texture	Taste	Flavor	Juiciness	Overall acceptability
1.	**0**							
2.	**15**	**0**						
3.	**15**	**4**						
4.	**15**	**20-22°C(Room Temperature)**						
5.	**30**	**0**						
6.	**30**	**4**						
7.	**30**	**20-22°C(Room Temperature)**						
8.	**45**	**0**						
9.	**45**	**4**						
10.	**45**	**20-22°C(Room Temperature)**						

9-Point Hedonic Scale

9 – Like Extremely
8 - Like Very Much
7 - Like Moderately
6 - Like Slightly
5 - Neither Like not Dislike
4 - Dislike Slightly
3 – Dislike Moderately
2 – Dislike Very Much
1 – Dislike Extremely

Signature of the Panelist

APPENDIX-II

Table 1. Effect of different cultivars, storage duration and temperatures oncolor of apple during storage

C / T / D	Color							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	7.67	7.67	7.67	**7.67**	7.67	7.67	7.67	**7.67**
D_2(15 days)	8.00	7.67	7.33	**7.67**	8.00	7.67	7.00	**7.56**
D_3(30 days)	8.33	8.00	7.00	**7.78**	8.00	6.00	6.67	**6.89**
D_4(45 days)	7.67	7.00	6.17	**6.94**	8.00	5.50	5.83	**6.44**
Mean(C×T)	**7.92**	**7.58**	**7.04**		**7.92**	**6.71**	**6.79**	
	Mean (C_1) 7.51				Mean (C_2) 7.14			
T / D	T × D			Mean (D)	$CD_{0.05}$			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	NS		
D_1 (0 day)	7.67	7.67	7.67	**7.67**	T	0.81		
D_2(15 days)	8.00	7.67	7.17	**7.61**	D	NS		
D_3(30 days)	8.17	7.00	6.83	**7.33**	C×T	NS		
D_4(45 days)	7.83	6.25	6.00	**6.69**	C×D	NS		
Mean(T)	**7.92**	**7.15**	**6.92**		T×D	NS		
					C×T×D	NS		

C- Cultivars; T – Storage Temperatures; D – Storage duration

Table 2. Effect of different cultivars, storage duration and temperatures ontexture of apple during storage

C / T / D	Texture							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	7.33	7.33	7.33	**7.33**	7.67	7.67	7.67	**7.67**
D_2(15 days)	8.00	7.33	7.00	**7.44**	8.33	7.33	7.00	**7.56**
D_3(30 days)	8.00	7.33	6.33	**7.22**	7.67	6.67	7.00	**7.11**
D_4(45 days)	8.00	7.17	6.17	**7.11**	7.67	6.33	6.00	**6.67**
Mean(C×T)	**7.83**	**7.29**	**6.71**		**7.83**	**7.00**	**6.92**	
	Mean (C_1)7.28				Mean (C_2)7.25			
T / D	T × D			Mean (D)	$CD_{0.05}$			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)		C	NS		
D_1 (0 day)	7.50	7.50	7.50	**7.50**	T	0.77		
D_2(15 days)	8.17	7.33	7.00	**7.50**	D	NS		
D_3(30 days)	7.83	7.00	6.67	**7.17**	C×T	NS		
D_4(45 days)	7.83	6.75	6.08	**6.89**	C×D	NS		
Mean(T)	**7.83**	**7.15**	**6.81**		T×D	NS		
					C×T×D	NS		

C- Cultivars; T – Storage Temperatures; D – Storage duration

Table 3. Effect of different cultivars, storage duration and temperatures ontaste of apple during storage

C / T / D	Taste							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	8.33	8.33	8.33	**8.33**	7.33	7.33	7.33	**7.33**
D_2(15 days)	8.67	8.33	7.33	**8.11**	8.00	7.33	7.00	**7.44**
D_3(30 days)	8.33	7.53	7.50	**7.79**	8.00	7.17	6.83	**7.33**
D_4(45 days)	8.00	6.80	6.00	**6.93**	8.00	7.00	6.33	**7.11**
Mean(C×T)	**8.33**	**7.75**	**7.29**		**7.83**	**7.21**	**6.88**	
	Mean (C_1) 7.79				Mean (C_2) 7.31			

T / D	T × D			Mean (D)
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	
D_1 (0 day)	7.83	7.83	7.83	**7.83**
D_2(15 days)	8.33	7.83	7.17	**7.78**
D_3(30 days)	8.17	7.35	7.17	**7.56**
D_4(45 days)	8.00	6.90	6.17	**7.02**
Mean(T)	**8.08**	**7.48**	**7.08**	

$CD_{0.05}$	
C	NS
T	0.73
D	NS
C×T	NS
C×D	NS
T×D	NS
C×T×D	NS

C- Cultivars; T – Storage Temperatures; D – Storage duration

Table 4 Effect of different cultivars, storage duration and temperatures onflavor of apple during storage

C / T / D	Flavor							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	8.00	8.00	8.00	**8.00**	7.00	7.00	7.00	**7.00**
D_2(15 days)	8.67	8.67	7.33	**8.22**	7.67	7.00	7.00	**7.22**
D_3(30 days)	8.33	7.53	7.50	**7.79**	8.00	7.17	6.50	**7.22**
D_4(45 days)	8.00	6.80	6.33	**7.04**	8.00	7.17	6.33	**7.17**
Mean(C×T)	**8.25**	**7.75**	**7.29**		**7.67**	**7.08**	**6.71**	
	Mean (C_1) 7.76				Mean (C_2) 7.15			

T / D	T × D			Mean (D)
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	
D_1 (0 day)	7.50	7.50	7.50	**7.50**
D_2(15 days)	8.17	7.83	7.17	**7.72**
D_3(30 days)	8.17	7.35	7.00	**7.51**
D_4(45 days)	8.00	6.98	6.33	**7.11**
Mean(T)	**7.96**	**7.42**	**7.00**	

$CD_{0.05}$	
C	NS
T	NS
D	NS
C×T	NS
C×D	NS
T×D	NS
C×T×D	NS

C- Cultivars; T – Storage Temperatures; D – Storage duration

Table 5. Effect of different cultivars, storage duration and temperatures onjuiciness of apple during storage

C / T / D	Juiciness							
	C_1 (Jeromine)				C_2 (Redlum Gala)			
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)	Mean (C×D)
D_1 (0 day)	7.33	7.33	7.33	**7.33**	8.33	8.33	8.33	**8.33**
D_2(15 days)	8.00	7.33	7.00	**7.44**	8.67	8.50	7.33	**8.17**
D_3(30 days)	8.00	7.50	6.33	**7.28**	8.33	7.53	8.00	**7.96**
D_4(45 days)	8.00	7.17	6.17	**7.11**	8.00	6.80	6.17	**6.99**
Mean(C×T)	**7.83**	**7.33**	**6.71**		**8.33**	**7.79**	**7.46**	
	Mean (C_1) 7.29				**Mean (C_2) 7.86**			

T / D	T × D			Mean (D)	$CD_{0.05}$	
	T_1 (0°C)	T_2 (4°C)	T_3 (Room Temperature)			
D_1 (0 day)	7.83	7.83	7.83	**7.83**	C	NS
D_2(15 days)	8.33	7.92	7.17	**7.81**	T	0.723
D_3(30 days)	8.17	7.52	7.17	**7.62**	D	NS
D_4(45 days)	8.00	6.98	6.17	**7.05**	C×T	NS
Mean(T)	**8.08**	**7.56**	**7.08**		C×D	NS
					T×D	NS
					C×T×D	NS

C- Cultivars; T – Storage Temperatures; D – Storage duration

APPENDIX-III

EXPERIMENT NO I:

ANOVA of fruit weight, physiological loss in weight, fruit volume and fruit density of apple fruits cv. Jeromine

Source of Variation	DF	MEAN SUM OF SQUARES (MSS)			
		Fruit weight(g)	Physiological loss in weight(%)	Fruit volume (cc)	Fruit density (g/cc)
Precooling (P)	3	121.81	31.95	155.84	0.000
Storage days (D)	4	5,051.75	2,856.30	4954.00	0.006
Interaction (P×D)	12	13.63	6.43	23.37	0.001
Error	40	4.96	1.63	9.72	0.000
Total	59				

ANOVA of firmness, TSS, titratable acidity and total sugars of apple fruits cv. Jeromine

Source of Variation	DF	MEAN SUM OF SQUARES (MSS)			
		Firmness (kg/cm^2)	TSS (°B)	Titratable acidity (%)	Total sugars (%)
Precooling (P)	3	0.46	0.12	0.00	15.32
Storage days (D)	4	85.00	20.59	0.01	5.88
Interaction (P×D)	12	0.01	0.90	0.00	2.69
Error	40	0.00	0.01	0.00	0.01
Total	59				

ANOVA of reducing sugars, non-reducing sugars, ascorbic acid content and anthocyanin content of apple fruits cv. Jeromine

Source of Variation	DF	MEAN SUM OF SQUARES (MSS)			
		Reducing sugars (%)	Non-reducing sugars (%)	Ascorbic acid content (mg/100g)	Anthocyanin content (A_{530}-OD)
Precooling (P)	3	5.96	1.96	3.05	0.16
Storage days (D)	4	0.78	2.50	11.99	0.42
Interaction (P×D)	12	0.86	0.57	0.27	0.01
Error	40	0.01	0.01	0.00	0.01
Total	59				

ANOVA of total phenols content and antioxidant activity of apple fruits cv. Jeromine

Source of Variation	DF	MEAN SUM OF SQUARES (MSS)	
		Total phenols (mg GAE/100g)	Antioxidant activity (%)
Precooling (P)	3	138.72	62.74
Storage days (D)	4	34,625.93	139.06
Interaction (P×D)	12	48.86	8.15
Error	40	20.88	1.44
Total	59		

EXPERIMENT NO II:

ANOVA of fruit weight, physiological loss in weight, fruit volume and fruit density of exotic cultivars of apple under different storage conditions.

Source of variation	Degree of freedom	Mean sum of squares			
		Fruit weight (g)	Physiological loss in weight (%- PLW)	Fruit volume(cc)	Fruit density(g/cc)
Cultivars (C)	1	8,988.38	126.673	9,373.60	0.009
Storage Temperatures(T)	2	459.91	185.135	666.756	0
Storage Time (D)	3	3,054.10	3,349.84	4,468.91	0.001
C×T	2	3.43	11.675	68.459	0.005
C×D	3	9.17	14.438	30.496	0.002
T×D	6	61.23	22.482	77.689	0
C×T×D	6	14.38	6.645	13.271	0.001
Error	48	0.76	0.389	4.633	0
Total	71				

ANOVA of firmness,TSS, titratable acidity and total sugars of exotic cultivars of apple under different storage conditions

Source of variation	Degree of freedom	Mean sum of squares			
		Firmness (kg/cm^2)	TSS (°B)	Titratable acidity (%)	Total sugars (%)
Cultivars (C)	1	25.55	78.54	0.30	27.31
Storage Temperatures(T)	2	36.18	1.56	0.01	9.10
Storage Time (D)	3	46.87	43.17	0.09	30.79
C×T	2	0.15	0.18	0.00	2.14
C×D	3	0.26	3.33	0.03	1.35
T×D	6	3.29	2.84	0.00	1.64
C×T×D	6	0.01	0.11	0.00	0.78
Error	48	0.00	0.02	0.00	0.00
Total	71				

ANOVA of reducing sugars, non-reducing sugars, ascorbic acid content and anthocyanin content of exotic cultivars of apple under different storage conditions

Source of variation	Degree of freedom	Mean sum of squares			
		Reducing sugars (%)	Non-reducing sugars (%)	Ascorbic acid content (mg/100g)	Anthocyanin content (A_{530}OD)
Cultivars (C)	1	15.11	1.62	0.68	0.62
Storage Temperatures(T)	2	3.93	1.12	2.69	0.30
Storage Time (D)	3	40.22	2.37	20.11	2.72
C×T	2	1.46	0.73	0.02	0.02
C×D	3	0.34	0.59	0.03	0.06
T×D	6	0.84	0.29	0.34	0.05
C×T×D	6	0.37	1.20	0.33	0.02
Error	48	0.00	0.00	0.00	0.00
Total	71				

ANOVA of total phenolscontent and antioxidant activity of exotic cultivars of apple under different storage conditions

Source of variation	Degree of freedom	Mean sum of squares	
		Total phenols (mg GAE/100g)	Antioxidant activity (%)
Cultivars (C)	1	157808.28	1.27
Storage Temperatures(T)	2	1063.04	46.87
Storage Time (D)	3	28197.06	116.97
C×T	2	8.89	2.46
C×D	3	3164.76	0.87
T×D	6	187.63	7.98
C×T×D	6	18.98	0.83
Error	48	3.77	0.01
Total	71		

ANOVA of colour, texture, taste,flavor,juiciness,overall acceptability of exotic cultivars of apple under different storage conditions

Source of variation	Degree of freedom	Mean sum of squares					
		Colour	Texture	Taste	Flavor	Juiciness	Overall acceptability
Cultivars (C)	1	2.53	0.01	4.25	6.72	5.84	1.62
Storage Temperatures(T)	2	6.59	6.50	6.09	5.54	6.00	8.14
Storage Time (D)	3	3.58	1.57	2.47	1.19	2.38	1.95
C×T	2	1.22	0.38	0.02	0.01	0.15	0.02
C×D	3	0.74	0.50	1.11	1.26	1.05	0.47
T×D	6	1.19	0.84	0.93	0.80	0.90	1.13
C×T×D	6	0.51	0.19	0.08	0.31	0.44	0.16
Error	48	1.93	1.76	1.57	1.74	1.55	1.50
Total	71						

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Title of Thesis	**:**	**"Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)"**
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ABSTRACT

The present investigation entitled "Effect of precooling and storage conditions on fruit quality of new exotic cultivars of apple (*Malus* × *domestica* Borkh.)" was carried out in the Department of Fruit Science, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the year 2022-23. The present study consists of two experiments. The first experiment was conducted to study the effect of different precooling methods on the storability of apple cv. Jeromine and consists of four pre-cooling treatments (P_1- Control; P_2 – Field cooling; P_3 – Hydro-cooling; P_4 – Air cooling) and five storage days (D_1 – 0 days; D_2 – 7 days; D_3- 14 days; D_4 – 21 days; D_5 – 28 days) and the fruits were stored at room temperature (20-22°C). The second experiment was conducted to study the storability of exotic cultivars of apple under different storage conditions. The experiment consists of two cultivars (C_1- Jeromine; C_2 - Redlum Gala), three storage temperature [T_1 -0˚C; T_2: 4˚C; T_3: Room Temperature (20-22°C] and four storage durations (D_1 – 0 days; D_2 – 15 days; D_3- 30 days; D_4 – 45 days). The experiments were replicated thrice and laid out in completed randomized block design (CRD). In first experiment, the results revealed that the lowest physiological weight loss (18.61 %), highest fruit firmness (4.60 kg/cm^2), TSS (11.48°B), total sugars (7.96 %), reducing sugars (4.37 %), ascorbic acid content (3.51 mg/100g), anthocyanin content (1.19 A_{530} – OD), total phenols content (475.82 mg GAE/100g) and antioxidant activities (85.39 %) was recorded in fruits treated with hydro-cooling. With respect to different storage days, the physiological weight loss, TSS and sugars increases and fruit firmness, ascorbic acid, total phenols and antioxidant activities decreases with prolonged storage. After 28 days of storage, the treatment combination of P_3D_5(Hydro-cooling + 28 days) recorded lowest physiological weight loss (35.86 %), highest fruit firmness (2.35 kg/cm^2), TSS (13.54°B), total sugars (9.20 %), reducing sugars (5.01 %), ascorbic acid content (2.50 mg/100g), anthocyanin content (1.06 A_{530} – OD), total phenols content (427.36 mg GAE/100g) and antioxidant activities (82.42 %) in comparison to all other treatment combination of precooling and storage days. In second experiment, the results depicted that the Jeromine cultivar recorded lowest physiological weight loss (12.84 %), highest fruit firmness (6.41 kg/cm^2), ascorbic acid content (3.36 mg/100g), anthocyanin content (1.43 A_{530} – OD), total phenols content (501.79 mg GAE/100g) and antioxidant activities (86.87 %) and Redlum Gala recorded highest TSS (13.21°B), total sugars (8.41 %) and reducing sugars (6.25 %) content. The fruits stored at temperature T_1(0°C) recorded lowest physiological weight loss (11.13 %), highest fruit firmness (6.77 kg/cm^2), TSS (12.42 °B), total sugars (8.44 %), reducing sugars (6.25 %), ascorbic acid content (3.63 mg/100g), anthocyanin content (1.45 A_{530} – OD), total phenols content (462.06 mg GAE/100 g) and antioxidant activities (88.28 %) in comparison to fruits stored at 4°C and room temperature. The treatment combination of $C_1T_1D_4$ (Jeromine + 0°C + 45 days) recorded lowest physiological weight loss (17.52 %), highest fruit firmness (6.07 kg/cm^2), ascorbic acid content (3.13 mg/100g), anthocyanin content (1.18 A_{530} – OD), total phenols content (480.83 mg GAE/100 g) and antioxidant activities (86.31 %) in comparison to all other treatment combinations after 45 days of storage. Hence from the present investigation it can be concluded that the hydro-cooling was found best precooling treatment, and the Jeromine cultivar in comparison to Redlum Gala when stored at 0°C retain better shelf life and fruit quality parameters.

Signature of Major Advisor **Signature of Student**

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