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Abstract:

Harvest maturity critically determines postharvest physiology, quality retention, and storage potential of apple fruit. This study investigated the influence of four harvest stages (H1–H4; 134–155 days from full bloom) on the postharvest quality of 'Red Chief' apples under ambient (21–22 °C, 68% RH) and refrigerated (2 °C, 95% RH) storage conditions. Fruits were evaluated over 60 days (ambient) and 150 days (refrigerated) for key physicochemical attributes including firmness, total soluble solids (TSS), titratable acidity, sugars, ascorbic acid, pectin, anthocyanins, juice content, physiological weight loss, and color characteristics. Storage duration significantly influenced all quality parameters. Starch degradation and TSS exhibited a biphasic pattern, with initial increases followed by declines due to metabolic substrate utilization. Firmness, acidity, pectin, ascorbic acid, and juice content decreased progressively, reflecting cell wall disassembly, organic acid metabolism, and moisture loss. Conversely, cumulative weight loss increased with storage duration, particularly under ambient conditions. Refrigerated storage effectively delayed metabolic degradation, preserving fruit quality and extending storage life. Among the harvest stages, fruits harvested at intermediate maturity (H3; 148 DFFB) showed superior retention of firmness, sugars, anthocyanins, and juice content, along with reduced physiological weight loss. These findings indicate that optimal harvest maturity ensures balanced metabolic activity and structural integrity during storage. Overall, harvesting at H3 combined with refrigerated storage is recommended as an effective strategy to maximize postharvest quality and extend shelf life of 'Red Chief' apples under North-Western Himalayan conditions.

Keywords: Post-harvest quality, Days from Full Bloom (DFFB), Storage conditions, Shelf life

1. Introduction

The apple (*Malus domestica* Borkh), a member of the Rosaceae family and the subfamily Pomoideae, is one of the most significant tree fruits globally (Ahmad et al., 2021). For the 2023/24 year, global apple production is expected to see a modest increase, rising by 175,000 metric tons to reach a total of 83.1 million tons (USDA, 2025). China remains the dominant producer, contributing approximately 40.5 million tons, which accounts for 47% of the world's total apple production. The United States follows with 6%, Turkiye with 3.61%, India with 3%, and Iran with 2%, rounding out the top apple-producing countries (Shah et al ., 2022).

Jammu and Kashmir is primarily known for its horticultural activities with around 75% of the rural population involved in the cultivation of temperate fruits. This sector is the most significant agricultural contributor in the region, accounting for nearly 8% of its GDP. According to the Directorate of Horticulture, apple farming alone supports the livelihoods of over 350,000 families (Sharma et al., 2023). Apples have been cultivated in Kashmir since ancient times, with several indigenous cultivars such as ‘Ambri’, ‘Kesari’, ‘Hazratbali’, and ‘Maharaji’ (Wani et al., 2023). Additionally, cultivars like ‘Golden Delicious’ and ‘Red Delicious’ have been introduced and have become commercially important. Comprehensive pre- and post-harvest research has been conducted on these cultivars, highlighting their vital role in the region's horticultural economy (Doryanizadeh et al ., 2017).

Recently, several exotic apple cultivars have been introduced in Kashmir from various European countries by SKUAST-K with the aim of increasing productivity, revitalizing the apple industry, and boosting the state's economy. These new cultivars are characterized by high productivity, suitability for high-density planting (HDP) and a short gestation period.

Due to these advantageous traits, there is significant demand for these cultivars among growers, prompting the state government to actively promote HDP on a large scale to further enhance apple production and productivity in Kashmir. Many progressive farmers have already embraced the cultivation of these exotic apple cultivars. However, there is a growing demand from orchardists for data on the storage behavior and optimal harvest dates for these new cultivars, as such information is currently lacking under Kashmir's specific conditions.

Choosing the optimal harvest date is essential for maintaining the post-harvest quality and extending the storage life of apple fruits (Shewa et al ., 2022) . Since fruit quality cannot be enhanced after harvest, it is primarily determined on the tree at the time of picking. The harvest timing plays a critical role in influencing essential fruit attributes like size and peel color, which are important for their market value (Chalise et al., 2019). Apples need to be harvested at the stage of maturity but before they are fully ripe. Picking them too early can lead to smaller fruits with diminished flavor and color, while also increasing their susceptibility to problems like scald, bitter rot, and internal breakdown (Sredojevic et al., 2025). Additionally, early-harvested apples experience greater mass loss due to water evaporation, as the cuticle, the protective outer layer, is not fully developed at this stage (Chalise et al., 2019).

Recent literature highlights the crucial role of harvest maturity in determining the post-harvest quality and shelf life of apples. Research has shown that harvesting at the optimal maturity stage is essential for maximizing storage duration and preserving fruit quality (Kailaku et al., 2023). While the significance of harvest maturity is well recognized, the choice of storage methods and conditions is also vital for preserving the quality of the fruit (Li et al., 2024). The objective of this study was to determine the optimal harvest date and investigate the post-harvest storage characteristics of the ‘Red Chief’ apple cultivar. By examining fruit harvested at four different maturity stages, this research seeks to provide

valuable insights into the best practices for harvesting and storing this exotic apple variety. The goal is to ensure maximum fruit quality and shelf life, benefiting both producers and consumers.

2. Materials and method

2.1 Procurement of raw material

The 'Red Chief' exotic apple cultivar, grown in the temperate regions of the Highland Himalayas, was selected as the raw material for this study. The apples were harvested at different maturity stages from a high-density orchard at SKUAST-K (34.1453° N, 74.8780° E) Shalimar, Srinagar, Jammu and Kashmir, India. Four harvest dates were chosen based on commercial maturity: H1 = 134 DFFB, H2 = 141 DFFB, H3 = 148 DFFB, and H4 = 155 DFFB. Apples harvested at various maturity stages were carefully sorted and placed into high-density polyethylene (HDPE) crates for further analysis. They were stored for 60 days under ambient conditions (21-22°C temperature, 68% relative humidity) and for 150 days in refrigerated storage (2°C temperature, 95% relative humidity). Quality assessments of the apples were performed at specific intervals: initially at 0 days, followed by evaluations at 10, 20, 30, 40, 50, and 60 days for those stored under ambient conditions, and at 30, 60, 90, 120, and 150 days for apples kept in refrigerated storage.

2.2 **Analysis of the physicochemical and sensory characteristics of apple (cv. Red Chief) throughout the storage period.**

2.2.1 Starch-iodine rating (1-6 point scale)

To evaluate maturity, one half of each apple was dipped into a solution consisting of 10 g of iodine crystals (I_2) and 25 g of potassium iodide (KI) dissolved in 1 liter of water. The pattern of starch breakdown is unique to each apple variety. Maturity is determined using a standardized color chart, with fruit staining rated on a scale from 1 (representing 100% starch content) to 6 (representing 0% starch) (Menesatti et al ., 2009) .

2.2.2 Firmness

The apples were positioned on a stable surface, and the probe of an Effegi hand-held penetrometer (FT 327) was inserted into the fruit to a depth of 8 mm, guided by a mark on the probe's shaft. The firmness of the fruit was then recorded using the penetrometer's scale, calibrated in newton (N)**.**

2.2.3 Hunter Lab colorimeter analysis

The surface color of the apples was assessed using the Hunter Lab Color Flex model A60–1012–312 (Hunter Associates Laboratory, Reston, VA). The device was calibrated with the manufacturer's standard white plate, and color variations were measured in the L*, a*, b* color space. In this system, L* indicates the lightness of the fruit's color, with values ranging from 0 (black) to 100 (white). The a* value reflects the color hue along a red-green axis, where positive values indicate red and negative values indicate green. The b* value represents the color hue along a yellow-blue axis, with positive values signifying yellow and negative values denoting blue (Shrestha et al., 2020).

2.2.4 Acidity (%)

Acidity was assessed through a titration method, with the results expressed as maleic acid [17] (Rangana, 1986). A 10 mL sample was diluted to a total volume of 100 mL using distilled water. The diluted sample was then titrated with a standard 0.1 N NaOH solution, employing phenolphthalein as an indicator, until a light pink color (the endpoint) was reached. The volume of NaOH utilized was noted, and the percentage acidity was calculated using the following formula:

$$\textbf{Acidity (\%)} = \frac{\textbf{Titre value} \text{ x normality of alkali xvolume made x67}}{\textit{weight of sample} \text{ x volume of aliquot takenx1000}} \text{x100} \qquad (1)$$

2.2.5 Pectin (%)

The pectin extraction method described by (Wani et al., 2023) was employed. Initially, 50 grams of whole apples were boiled in 300 mL of 0.01 mol/L HCl for approximately 30 minutes, followed by filtration. The solid residue was then rinsed with hot water. Next, the residue was treated with 100 mL of 0.05 mol/L HCl and boiled for an additional 20 minutes before being washed again with hot water. This procedure was repeated one final time using 100 mL of 0.03 mol/L HCl, which was boiled for 10 minutes. The filtrates from all stages were combined, and the total volume was adjusted to 500 mL A sample of 100–200 mL was taken, to which 250 mL of water was added. The mixture was neutralized with sodium hydroxide (NaOH), followed by the addition of 10 mL of 1 mol/L NaOH in excess. The solution was left to stand overnight. After this resting period, 50 mL of 1 mol/L acetic acid was added, and after 5 minutes, 25 mL of 1 mol/L calcium chloride ($CaCl_2$) was introduced. The mixture was allowed to sit for 1 hour and then boiled for 2 minutes. Finally, the solution was filtered through Whatman No. 1 filter paper, and the resulting material was dried. Pectin, in the form of calcium pectate, was quantified using the equation below.

$$\text{Calcium pectate } (\%) = \frac{weight\ of\ calcium\ pectate \times 500}{ml\ of\ filetrate\ taken \times \text{weight of sample}} \times 100 \qquad (2)$$

2.2.6 Total soluble solids

Total Soluble Solids (TSS) were determined using a digital hand-held refractometer (ATAGO, Japan) that was calibrated with distilled water. Two drops of fresh juice were applied to the lens of the refractometer, and the measurement was taken. The readings were then adjusted to correspond to a temperature of 20°C and reported as 'degrees Brix' (°Brix).

2.2.7 Anthocyanin Content

Anthocyanins were quantified following the procedure outlined by (Rangana, 1986). A 10 mL sample was diluted to 100 mL with ethanolic HCl (a solution of 95% ethanol and 1.5 N HCl) and then stored in a refrigerator at 4°C overnight. After refrigeration, the mixture was filtered through Whatman No. 1 filter paper. The resulting filtrate was transferred into a cuvette, and its Optical Density (O.D.) was measured at 535 nm using a spectrophotometer. The blank used for the measurement was 95% ethanol. The total anthocyanin content was determined using specific equations:

Total Optical Density (O.D) $= \frac{OD\ at\ 535 \text{x} \text{volume made}}{weight\ of\ sample\ taken} \text{x} 100$

Total Anthocyanin (mg/100g) $= \frac{\boldsymbol{Total\ O.D}}{\mathbf{98.2}}$ **(3)**

2.2.8 Ascorbic acid (mg/100g)

Ascorbic acid content was measured using the 2,6-Dichlorophenol-Indophenol visual titration method, as described by (Rangana ,1986). A 10 mL juice sample was diluted to 100 mL using a 3% phosphoric acid (H_3PO_4) solution. From this diluted solution, 10 mL was taken and transferred into a beaker for titration with a standardized 2,6-Dichlorophenol-Indophenol dye. Titration continued until a light pink color remained visible. The volume of dye used was recorded, and the procedure was repeated three times, with the average value calculated.

Ascorbic acid (mg/100 g) $= \frac{\text{Titre value x dye factor x volume made}}{\text{Volume of filtrate taken x weight of sample}} \text{x} 100$ (4)

2.2.9 Juice content (%)

Juice was extracted from 10 randomly selected fruits from each harvest using a juice extraction machine. The yield was then calculated using the following equation:

Per cent juice $= \frac{Weight\ of\ juice\ fruit}{total\ weight\ of\ fruits\ taken} \text{x}\ 100$ (5)

2.2.10 Analysis of sugars

Total sugars were estimated following the Lane and Eynon method (Rangana, 1986). For total sugar estimation, 10 mL of the sample was diluted with around 50 mL of distilled water and neutralized with 1N sodium hydroxide, using phenolphthalein as an indicator. To this neutralized solution, 2 mL of 45% lead acetate was added. After allowing it to stand for 5-10 minutes, 2 mL of 42% potassium oxalate was added to precipitate the excess lead acetate, and the solution was then filtered. Fifty mL of the filtrate was hydrolyzed by adding 10 mL of hydrochloric acid (1:1) and left to stand overnight to ensure complete hydrolysis. The next day, the excess hydrochloric acid was neutralized using a saturated sodium hydroxide solution. The hydrolyzed portion was placed in a burette and titrated against a boiling mixture of 5 mL each of Fehling's solutions A and B, with methylene blue as the indicator (AOAC, 1990). The titration endpoint was indicated by the formation of a brick-red precipitate. The results were expressed as a percentage using the following equation:

$$\text{Total Sugars (\%)} = \frac{0.05 \text{x volume made x } 100}{titre\ value \text{ x volume of sample}} \qquad (6)$$

2.2.11 Cumulative physiological loss in weight (%, CPLW)

To determine the Cumulative Physiological Loss in Weight (CPLW), ten fruits from each harvest were weighed immediately after harvesting to record their original weight. At each analysis interval, the fruits were re-weighed. The CPLW was subsequently calculated and expressed as a percentage using the following formula.

$$\text{CPLW (\%)} = \frac{Original\ weight - subsequent\ weight\ at\ analysis}{Original\ weight} \text{ x } 100 \qquad (7)$$

2.3 Organoleptic evaluation

2.3.1 Sensory evaluation

For the sensory evaluation of Red Chief apples harvested at various maturity stages and stored under both ambient and refrigerated conditions. The evaluation focused on attributes

such as juiciness, crispness, tenderness, mealiness, and appearance, using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Sensory evaluation was conducted using a trained panel of 10 members from the Division of Food Science & Technology, SKUAST-K, J&K, India. No external human participants were involved in this study. Prior to the evaluation, all panelists were informed about the study objectives, testing procedures, and evaluation criteria. Written informed consent was obtained from all panelists before participation. Panelists were trained in sensory testing methods and rating procedures. Randomly coded samples were then presented for evaluation under controlled conditions.

2.4 Data presentation

To enhance readability and facilitate clear interpretation, the experimental data were graphically represented using OriginPro software (version 9.8). The results are presented descriptively based on observed trends.

2.4 Statistical analysis

The experiments were carried out in triplicate, and the data presented represent the average of these three measurements. To enhance readability, the data were graphically represented using Origin Pro Software (version 9.8).

3. Results and discussions

3.1 Effect of different maturity levels and storage conditions on starch-iodine rating

In apples, starch plays an important role in maintaining cell turgor and firmness, making it a crucial marker of harvest maturity. During post-harvest storage, amylase breaks down starch into sugars, which serve as key substrates for respiration (Ding et al., 2024). Figure 1(a) illustrates how varying harvest dates and storage conditions impact the starch-iodine rating in the Red Chief apple cultivar. At the start of storage (0 days), the mean starch-iodine ratings were recorded as 2.00, 2.70, 3.50, and 4.70 for harvest dates H1, H2, H3, and H4, respectively. Over time, these ratings increased, reaching a maximum of 6.00 by the 20th day under ambient

conditions, and similarly reaching 6.00 by the 60th day in refrigerated storage. Notably, apples harvested later (H3 and H4) exhibited the highest starch-iodine ratings during both ambient and refrigerated storage conditions. This trend underscores the relationship between apple maturity and starch degradation, as both prolonged storage and higher maturity levels consistently led to a reduction in starch content (Zhang et al ., 2021). Studies have similarly reported substantial decreases in starch content across different apple cultivars stored under both ambient and cold conditions (Wani et al., 2024). This pattern confirms that starch breakdown is strongly governed by both harvest maturity and storage temperature, where delayed harvesting accelerates postharvest metabolic transitions.

3.2 Effect of different maturity levels and storage conditions on fruit firmness (N)

Fruit firmness is strongly associated with the texture of the flesh and the structural modifications taking place in the primary cell wall during the ripening process (Zhang et al 2019). Figure 1(b) illustrates how harvest dates and storage conditions influence the fruit firmness of the Red Chief apple cultivar. At the start of storage (0 days), the highest fruit firmness values were recorded as 79.83N, 71.62N, 70.92N, and 65.83N for harvests H1, H2, H3, and H4, respectively. Over time, these values declined, reaching 31.23N, 31.37N, 39.14N, and 31.14N at the end of 60 days of ambient storage. In contrast, after 150 days of refrigerated storage, firmness values were recorded as 41.59N, 41.37N, 42.26N, and 40.93N for H1, H2, H3, and H4, respectively. Among all harvest dates, H3 exhibited the least decline in firmness in both ambient and refrigerated storage conditions. Research by (Kailaku et al., 2023) emphasized the importance of harvesting apples at the optimal maturity stage to maximize storage duration and maintain fruit quality. During ripening, hemi-cellulosic and pectic polymers in the cell wall undergo significant enzymatic breakdown, weakening the cell-to-cell adhesion, which in turn reduces the rigidity of the cell wall, resulting in a loss of firmness (Mohebbi et al., 2020). Susaj et al. (2014) reported that after 180 days of cold storage, a 30.4% decrease in firmness was recorded. In general, a more pronounced reduction in firmness was observed in apples stored under ambient conditions compared to refrigerated storage. The relatively minor firmness reduction in apples from H3 may be attributed to the full development of the epicuticular layer, which provides better protection (Zhang et al., 2020). These results align with earlier studies that indicated a more significant loss of firmness during ambient storage compared to refrigerated conditions (Ahmad et al., 2021).

These findings emphasize that harvest timing determines susceptibility to texture loss, while cold storage mitigates softening by suppressing cell wall-modifying enzymes.

3.3 Effect of different maturity levels and storage conditions total soluble solids (°Brix)

Total soluble solids (TSS) are a key indicator of fruit quality and consumer acceptance, closely linked to sweetness and the overall flavor profile—essential factors that influence consumer preference (Harker et al., 2008). Figure 1(c) highlights the impact of harvest dates and storage conditions on the TSS levels in the Red Chief apple cultivar. At the start of storage (0 days), the lowest TSS values were recorded as 10.15 °Brix, 10.57 °Brix, 11.39 °Brix, and 12.03 °Brix for harvests H1, H2, H3, and H4, respectively. Over the first 30 days of ambient storage, TSS values increased to 11.15 °Brix, 11.37 °Brix, 11.97 °Brix, and 12.63 °Brix, before gradually decreasing to 10.00 °Brix, 10.80 °Brix, 11.00 °Brix, and 11.02 °Brix by the end of the storage period. Similarly, under refrigerated storage conditions, TSS values also rose initially, reaching 10.65 °Brix, 11.27 °Brix, 11.59 °Brix, and 12.33 °Brix for H1, H2, H3, and H4 after 90 days of storage. However, a slight decline followed, with values settling at 10.35 °Brix, 10.87 °Brix, 11.42 °Brix, and 12.07 °Brix after 150 days of refrigeration. Notably, apples harvested at H3 exhibited the least reduction in TSS across both ambient and refrigerated storage conditions. The initial rise in TSS during storage is typically attributed to the ripening process, which involves the conversion of starches into sugars, enhancing sweetness. The subsequent decline in TSS can be linked to substrate depletion or over-ripening as the fruit matures (Sachan, & Kumar, 2022). These results align with previous findings, which also reported an increase in TSS during the early stages of storage, followed by a gradual decrease as storage duration extended (Topno et al., 2023). This behavior confirms that TSS is a dynamic indicator of ripening metabolism, closely linked to carbohydrate turnover.

3.4 Effect of different maturity levels and storage conditions acidity (%)

Titratable acidity (TA) plays a critical role in determining apple maturity and consumer satisfaction, as it directly affects the fruit's taste profile (Mac Kenzie et al., 2021). Malic acid, the primary acid in apples, is responsible for the tartness (Ma et al., 2018), and its content decreases as metabolic activities like respiration slow down (Brizzolara et al., 2020). Figure 1(d) illustrates the effect of harvest dates and storage conditions on the acidity of the Red Chief apple cultivar. At the start of storage (0 days), the highest acidity values were recorded as 0.335%, 0.315%, 0.290%, and 0.260% for harvests H1, H2, H3, and H4, respectively. These values showed a noticeable decline by the end of 60 days of ambient storage, dropping to 0.150%, 0.120%, 0.115%, and 0.100%. In contrast, under refrigerated storage, the decrease in acidity was less pronounced, with values reducing to 0.220%, 0.240%, 0.235%, and 0.195% for H1, H2, H3, and H4, respectively. The reduction in organic acids, particularly malic acid, occurs as apples ripen, and lower storage temperatures help slow this decline, thus preserving the titratable acidity for a longer period. These findings are consistent with earlier studies, which also noted that acidity levels tend to be lower in apples from later harvests compared to those from earlier ones (Thewes et al., 2017). Additionally, the variation in titratable acidity across different storage conditions, with a more gradual decrease in refrigerated environments, supports the results observed in this study (Wani et al ., 2024) .

3.5 Effect of different maturity levels and storage conditions on total sugars (%)

The sugar composition in apples mainly consists of sucrose, fructose, and glucose, with the right balance of these sugars being essential for maintaining fruit quality. Figure 1(e) illustrates the effect of harvest dates and storage conditions on the total sugar content of the Red Chief apple cultivar. At the beginning of storage (0 days), the lowest total sugar values were recorded as 8.62%, 8.98%, 9.68%, and 10.22% for harvests H1, H2, H3, and H4, respectively. After 30 days of ambient storage, these values increased to 9.47%, 9.66%, 10.17%, and 10.74%, before gradually declining to 7.00%, 7.30%, 9.00%, and 8.90% by the

end of the storage period. Similarly, under refrigerated storage, total sugar content also increased initially, reaching 9.05%, 9.58%, 9.85%, and 10.48% for H1, H2, H3, and H4 after 90 days. However, a subsequent decline was observed, with values settling at 8.79%, 9.23%, 9.70%, and 10.26% after 150 days of refrigeration. Among the harvests, H3 showed the least reduction in sugar content in both ambient and refrigerated storage conditions. The rise in total sugars during the initial storage stages is due to the hydrolysis of starch into simpler sugars, such as glucose and fructose. Additionally, the breakdown of complex cell wall polysaccharides may contribute to the rise in total sugar content. However, prolonged storage leads to a gradual decline in sugar levels, as these sugars are utilized in the metabolic processes of the apples (Zhang et al., 2019). The observed trends are in line with prior research that reported sugar levels rising during the first 90 days of cold storage, subsequently followed by a gradual reduction (Zhao et al ., 2019). Batkan et al. (2012) reported that after few months of storage, the apples' starch content was entirely changed into glucose and maltose. And due to prolonged storage, glucose and maltose were used for performing metabolic activity of the apples. According to Wani et al. (2024) apples exhibited a slight increase in total sugar content, which was subsequently followed by a gradual decline under both ambient and refrigerated storage conditions.

3.6 Effect of different maturity levels and storage conditions on ascorbic acid (mg/100g)

Ascorbic acid, recognized as vitamin C, is an essential nutrient known for its powerful antioxidant effects that neutralize reactive oxygen species (ROS). Beyond its health benefits, it also helps to enhance the shelf life of apples (Fang et al., 2017). Figure 1(f) illustrates the effect of different harvest dates and storage conditions on the ascorbic acid content of the Red Chief apple cultivar. At the start of storage (0 days), the ascorbic acid content was recorded as 7.32 mg/100g, 7.50 mg/100g, 7.58 mg/100g, and 7.75 mg/100g for H1, H2, H3, and H4, respectively. However, these values decreased after 60 days of ambient storage, falling to

4.80 mg/100g, 5.00 mg/100g, 5.10 mg/100g, and 5.08 mg/100g. In refrigerated storage, the decrease was even more pronounced, with the ascorbic acid content dropping to 3.00 mg/100g, 3.01 mg/100g, 3.02 mg/100g, and 3.02 mg/100g after 150 days. Previous studies have reported a similar decrease in ascorbic acid levels, with 'King Jonagold' apples stored at 1ºC experiencing an 80% reduction in vitamin C content after three months. This decline was observed in apples kept in ultra-low oxygen-controlled atmospheres (0.9% O_2; 1.2% CO_2) as well as those treated with 1-MCP. Similar trends were reported for other apple cultivars, including ‘Golden Delicious’ and ‘Red Delicious’. The significant decrease in ascorbic acid over time, especially under cold storage conditions, is attributed to the degradation of ascorbic acid during extended storage at low temperatures. This reduction affects both the nutritional quality and shelf life of the apples, underscoring the necessity for optimal storage practices to preserve maximum ascorbic acid content (Kevers et al., 2011; Ferreira et al., 2024). Therefore, ascorbic acid serves as a sensitive indicator of oxidative stress during storage.

3.7 Effect of different maturity levels and storage conditions on pectin content (%)

Pectin is a vital polysaccharide found in the primary cell wall and middle lamella, contributing to cell adhesion and structural integrity. It also facilitates cell separation during certain developmental stages, which affects the texture and firmness of the fruit (Daher et al., 2015). Figure 1(g) illustrates the effect of harvest dates and storage conditions on the pectin content of the Red Chief apple cultivar. At the start of storage (0 days), the pectin content was recorded at 0.95%, 0.90%, 0.83%, and 0.65% for harvests H1, H2, H3, and H4, respectively. However, after 60 days of ambient storage, these values decreased to 0.19%, 0.17%, 0.19%, and 0.08%. Under refrigerated storage, the reduction was less drastic but still notable, with pectin levels dropping to 0.34%, 0.30%, 0.27%, and 0.12% after 150 days. The decline in pectin content during storage, whether ambient or refrigerated, is associated with the natural

ripening process. As apples ripen, the cell walls loosen, and pectin solubilizes due to the loss of galactosyl residues, resulting in reduced cell cohesion and a softer fruit texture. This process is a key factor in the softening of the fruit, which affects both its quality and marketability over time (Brummell, 2006).. Similar findings were reported in other apple cultivars such as 'Green Ball' and 'Summer King,' where pectin levels significantly decreased during storage (Win et al., 2019). The results demonstrate that pectin degradation is a consistent outcome across different apple cultivars as they mature and are stored, impacting their overall texture and shelf life.

3.8 Effect of different maturity levels and storage conditions on anthocyanins (mg/100g)

The red color of apple skin is largely due to anthocyanins, particularly cyanidin-3-galactoside (idaein), which is the dominant anthocyanin present in apples (Dar et al., 2019). Figure 1(h) illustrates the effect of different harvest dates and storage conditions on the anthocyanin levels in the Red Chief apple cultivar. At the start of storage (day 0), anthocyanin content measured 28.10 mg/100g, 31.20 mg/100g, 34.20 mg/100g, and 37.40 mg/100g for harvests H1, H2, H3, and H4, respectively. After 30 days of ambient storage, these values increased to 28.90 mg/100g, 31.70 mg/100g, 34.42 mg/100g, and 37.70 mg/100g, followed by a reduction to 27.30 mg/100g, 29.11 mg/100g, 33.50 mg/100g, and 35.68 mg/100g by the end of storage. In refrigerated storage, anthocyanin content initially rose to 26.50 mg/100g, 30.10 mg/100g, 33.10 mg/100g, and 31.27 mg/100g after 90 days, but decreased thereafter to 26.00 mg/100g, 28.80 mg/100g, 32.95 mg/100g, and 35.55 mg/100g by day 150. Notably, H3 exhibited the least decline in both storage conditions. Ganai et al. (2015) reported that anthocyanin content increases from the bud stage to full maturity during fruit ripening. However, as fruits enter the senescence phase, anthocyanins degrade, leading to a decline in their concentration. This reduction in anthocyanin levels can be linked to aging and other cellular processes. These

findings are consistent with those of Wani et al. (2024) confirming the relationship between anthocyanin degradation and storage conditions.

3.9 Effect of different maturity levels and storage conditions on juice content (%)

Juice content in apples is primarily determined by the fruit's water content and the rate of water loss over time (Zhang et al., 2019). Figure 1(i) shows the effect of harvest dates and storage conditions on the juice content of the Red Chief apple cultivar. At the beginning of storage (0 days), the highest juice content values were recorded as 63.00%, 65.20%, 67.32%, and 65.57% for harvests H1, H2, H3, and H4, respectively. However, after ambient storage, these values declined to 26.90%, 33.63%, 40.02%, and 32.51%. In refrigerated storage, the decrease was more gradual, with juice content reducing to 50.20%, 53.02%, 56.50%, and 54.40% after 150 days. Interestingly, harvest H3 exhibited the least reduction in juice content under both ambient and refrigerated storage conditions. This could be attributed to the development of a more robust epicuticular layer, which helps reduce water loss and preserve juice content. Since juice content is directly related to the fruit's water retention capacity, a more developed epicuticular layer may play a significant role in slowing the decline (Harker et al., 2008). Previous studies have also shown that harvest stages influence juice content across various apple cultivars (Wani et al., 2023). The reduction in juice content is primarily driven by water loss from the fruit, which occurs during both ambient and cold storage. Our findings align with earlier research, which reported a similar decline in apple juice content, from 59.27% to 43.3%, over time. This reinforces the understanding that water retention and its loss are the key factors influencing juice content in apples.

3.10 Effect of different maturity levels and storage conditions on Cumulative Physiological Loss of Weight (CPLW)

Excessive water loss is a common issue in the long-term storage of apples, significantly

affecting their marketability. A reduction in water content decreases the crop's marketable weight, and a loss exceeding 6% typically results in an unappealing, shriveled appearance (Hatfield et al., 1988; Hasan et al., 2024). Figure 1(j) shows the effect of harvest dates and storage conditions on the cumulative physiological loss of weight (CPLW) in the 'Red Chief' apple cultivar. CPLW was first observed after 10 days of ambient storage and 30 days of refrigerated storage. The initial CPLW values at 10 days of ambient storage were recorded as 1.41%, 2.08%, 3.17%, and 3.20% for harvests H1, H2, H3, and H4, respectively. These values increased by the end of 60 days, reaching 13.10%, 9.90%, 8.90%, and 10.24%. In contrast, under refrigerated storage conditions, the CPLW values started at 1.85%, 1.56%, 1.30%, and 1.29% after 30 days and increased to 6.16%, 5.20%, 4.69%, and 4.78% at the end of 150 days. The comparatively lower increase in CPLW in H3, especially in refrigerated conditions, may be attributed to the development of the epicuticular layer, which helps to minimize water loss. This layer acts as a barrier, reducing transpiration and thus limiting the overall weight loss (Harker et al., 2008). Previous studies support these findings, showing that apples, such as the 'Golden Delicious' cultivar, stored in refrigerated conditions experience clearly less weight loss than those stored at room temperature (Ferreira et al., 2024). Moreover, ethylene production is known to play a crucial role in the ripening and senescence of apples, contributing to weight loss during storage. Reducing ethylene levels can help in mitigating CPLW, enhancing the shelf life and appearance of stored apples (Onik et al., 2021).

3.11 Effect of different maturity levels and storage conditions on L* a* b* parameters

Color is a key quality attribute that significantly influences the appearance and consumer appeal of apples (Ahmad et al., 2021). The Hunter Lab color parameters (L*, a*, b*) reflect these changes during storage. Figure 1(k) shows the effect of harvest dates and storage conditions on the L* values (lightness) of the Red Chief apple cultivar. At 0 days of storage,

L* values were recorded as 34.50, 35.00, 36.78, and 37.80 for H1, H2, H3, and H4, respectively. After ambient storage, these values dropped to 25.00, 25.90, 28.10, and 27.00, indicating a loss of lightness. Under refrigerated storage, the decline in L* values was less pronounced but still notable, decreasing to 29.70, 30.52, 32.32, and 33.32 by the end of 150 days. Figure 1(l) illustrates the effect on a* values, which reflect the red-green color spectrum. At the beginning of storage, a* values were 13.50, 14.54, 16.56, and 17.60 for H1, H2, H3, and H4. These values decreased to 8.90, 9.00, 10.45, and 9.80 by the end of ambient storage, signalling a reduction in the redness of the apples. In refrigerated conditions, a* values also decreased, but less dramatically, to 10.60, 11.43, 14.16, and 15.20 at the end of 150 days. Figure 1(m) illustrates the effect on b* values, which measure the yellow-blue spectrum, also showed evident changes during storage. Initially, b* values were 29.56, 28.60, 27.30, and 27.23 for H1, H2, H3, and H4. After ambient storage, these values increased to 35.00, 32.90, 31.50, and 34.49, indicating an increase in the yellow hue. Under refrigerated conditions, b* values rose more moderately, reaching 33.11, 31.85, 30.20, and 30.38 by the end of 150 days. These changes indicate that throughout the storage period, apples became progressively duller, with a decrease in their red color and an increase in their yellow hue. As a result, they became less visually appealing over time (Ahmad et al., 2021). These findings are consistent with other studies, which observed similar shifts in L*, a*, and b* values in apple cultivars like ‘Golden Delicious’, ‘Red Delicious’, and ‘Ambri’ (Ahmad et al., 2021). . The degradation in color during storage is a well-documented phenomenon that affects the overall marketability of apples.

3.12 Effect of different maturity levels and storage conditions on organoleptic properties

The primary determinants of consumer acceptability and shelf life of apples are largely based on sensory evaluations (Wani et al., 2023). Figure 2 illustrates the impact of harvest dates and storage conditions on the overall acceptability of juice from the Red Chief apple cultivar.

Initial acceptability values of 7.24, 7.50, 8.50, and 8.70 were recorded at day 0 of storage. These values showed a significant decline after 60 days of ambient storage, dropping to 3.50, 4.00, 6.20, and 6.00 for H1, H2, H3, and H4 harvest dates, respectively. In contrast, when stored under refrigerated conditions for up to 150 days, the decrease in acceptability was more gradual, with values falling to 5.70, 6.21, 7.99, and 7.60, respectively. Similar results were observed in the ambient and cold storage of other cultivars such as ‘Gala Redlum’, ‘Red Velox’, and ‘Super Chief’, harvested at three different maturity levels 6 (Wani et al., 2023). Our findings are consistent with previous studies that show overall acceptability of apples tends to decline with prolonged storage time (Ahmad et al., 2021). For instance, sensory acceptability (as assessed by both expert panels and consumers) decreased for 'Jonagold' and 'Gala' apples stored beyond one month in cold storage. Another study highlighted a significant reduction in consumer acceptability for 'Fuji' apples after 28 days at 20°C following refrigerated storage, with the most common quality losses being increased mealiness and the development of alcoholic taste and odor (Varela et al., 2005). Moreover, similar trends have been reported for 'Golden Delicious' and 'Idared' apples. 'Golden Delicious' apples stored under ultra-low oxygen (ULO) conditions were found to maintain better quality compared to those stored in a normal atmosphere (NA) (Korićanac et al., 2019), underscoring the importance of storage conditions in preserving apple quality during shelf life.

4. Conclusion

This study demonstrates that harvest maturity and storage conditions interactively regulate the postharvest physiology and quality evolution of ‘Red Chief’ apples. Fruits harvested at intermediate maturity (H3; 148 DFFB) exhibited superior retention of textural, biochemical, and sensory attributes, indicating an optimal balance between physiological development and metabolic stability. Early-harvested fruits showed accelerated weight loss and inferior quality retention, while late-harvested fruits exhibited rapid senescence-associated deterioration.

Refrigerated storage (2 °C, 95% RH) significantly delayed ripening-associated metabolic processes, including starch hydrolysis, organic acid depletion, and cell wall degradation, thereby extending storage life up to 150 days compared to rapid deterioration under ambient conditions. The observed decline in firmness, pectin, acidity, and ascorbic acid, along with increased weight loss, highlights the central role of respiration, enzymatic activity, and water loss in postharvest deterioration. From a practical perspective, harvesting at optimal maturity combined with low-temperature storage offers a viable strategy to enhance shelf life, maintain nutritional quality, and reduce postharvest losses. Future research should focus on integrating advanced storage technologies such as controlled atmosphere (CA), modified atmosphere packaging (MAP), and postharvest treatments (e.g., 1-MCP, edible coatings) to further modulate metabolic activity and improve quality retention. Additionally, molecular-level studies on ripening-associated enzymes and stress physiology could provide deeper insights into cultivar-specific storage responses.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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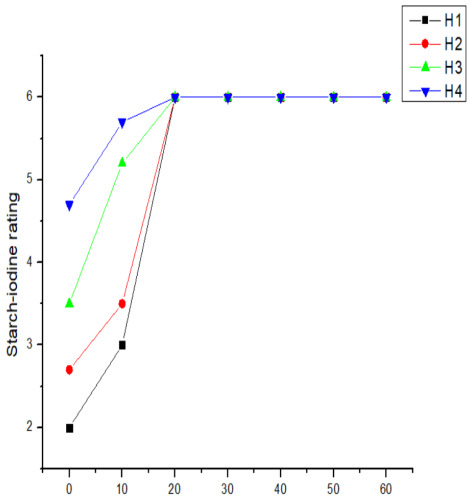
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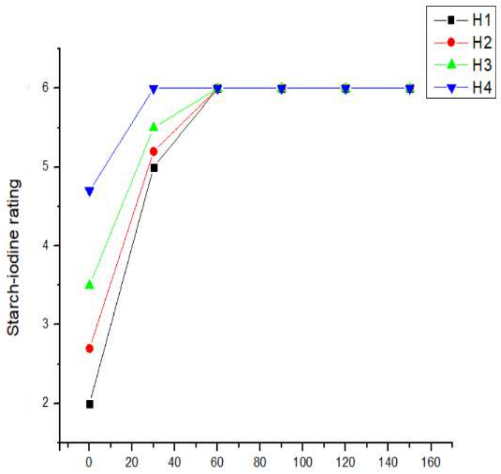
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(a)

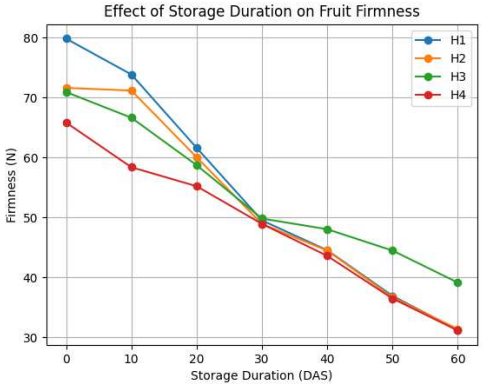


Storage period under ambient conditions (days)

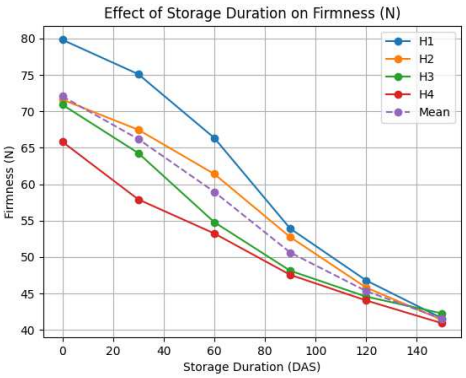


Storage period under refrigerated conditions (days)

(b)

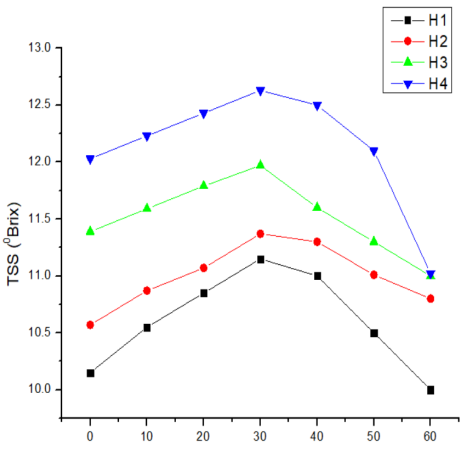


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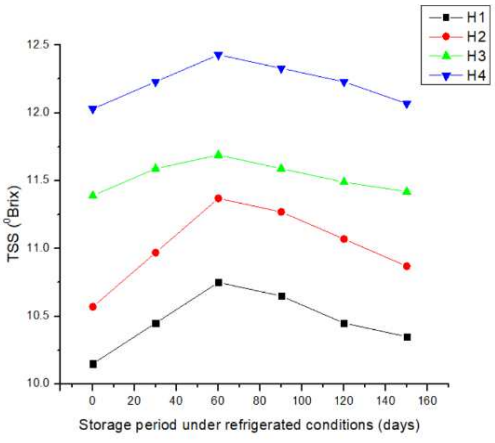


Storage period under refrigerated conditions (days)

(c)

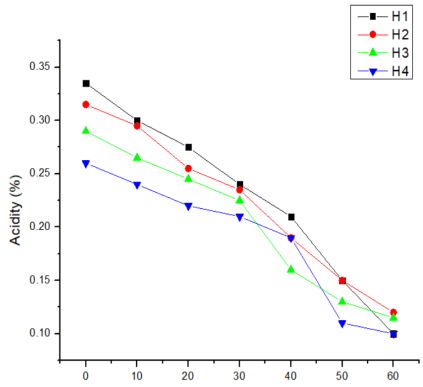


Storage period under ambient conditions (days)

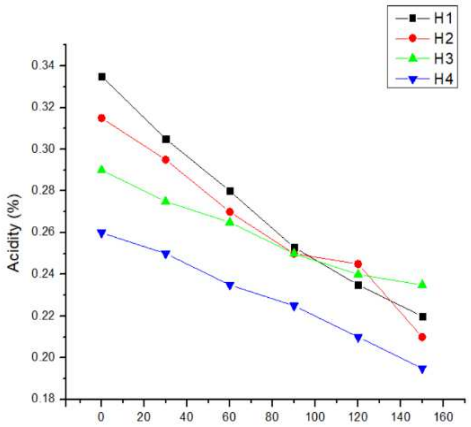


Storage period under refrigerated conditions (days)

(d)

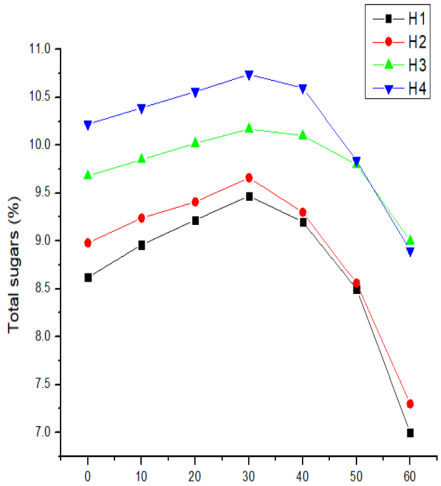


Storage period under ambient conditions (days)

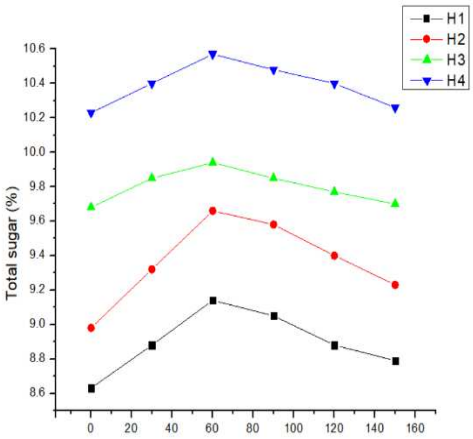


Storage period under refrigerated conditions (days)

(e)

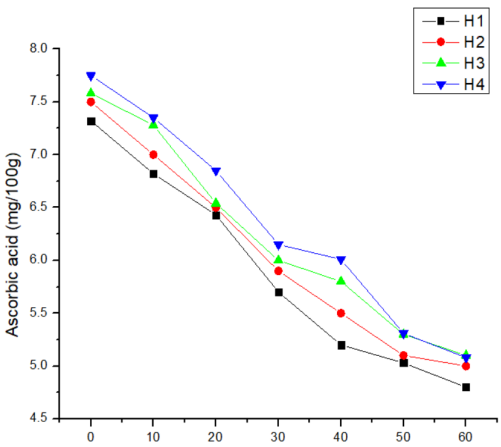


Storage period under ambient conditions (days)

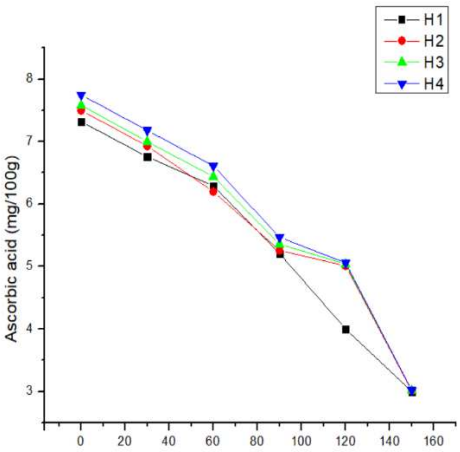


Storage period under refrigerated conditions (days)

(f)

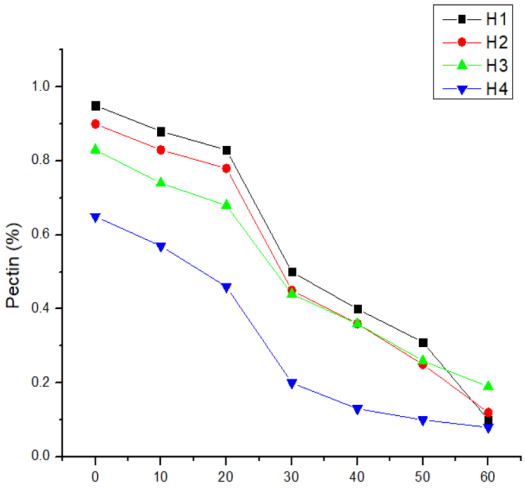


Storage period under ambient conditions (days)

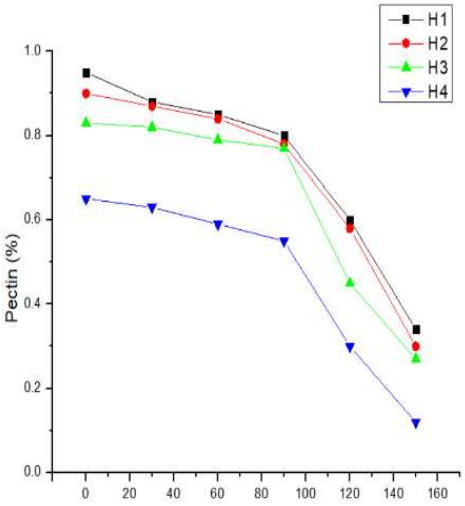


Storage period under refrigerated conditions (days)

(g)

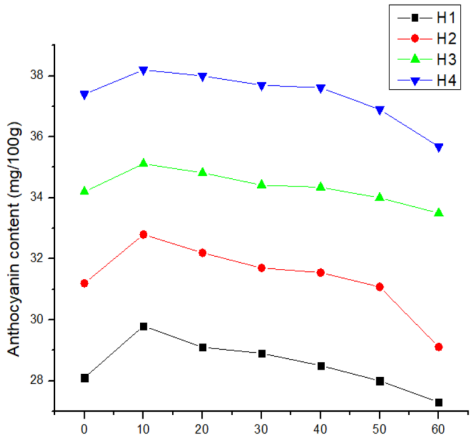


Storage period under ambient conditions (days)

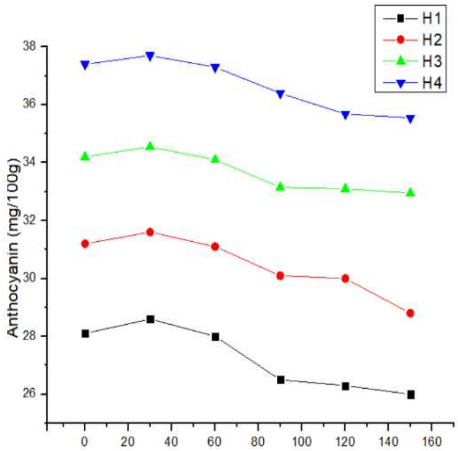


Storage period under refrigerated conditions

(h)

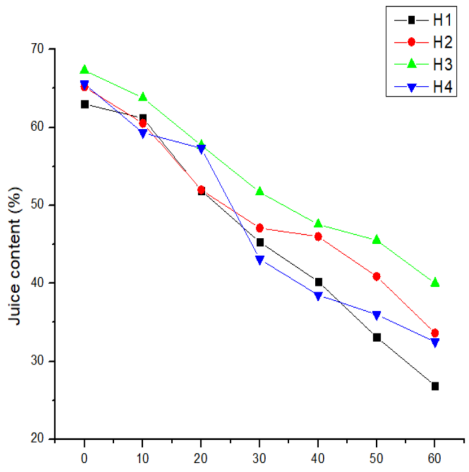


Storage period under ambient conditions (days)

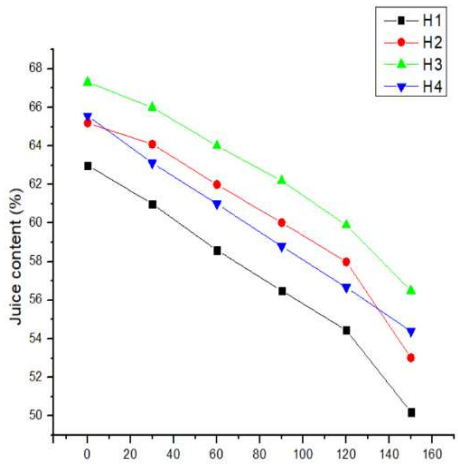


Storage period under refrigerated conditions (days)

(i)

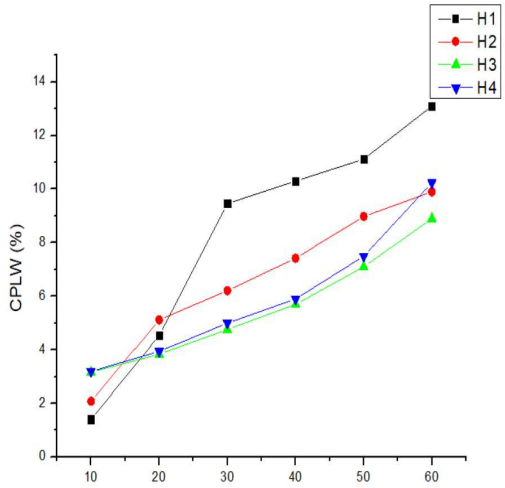


Storage period under ambient conditions (days)

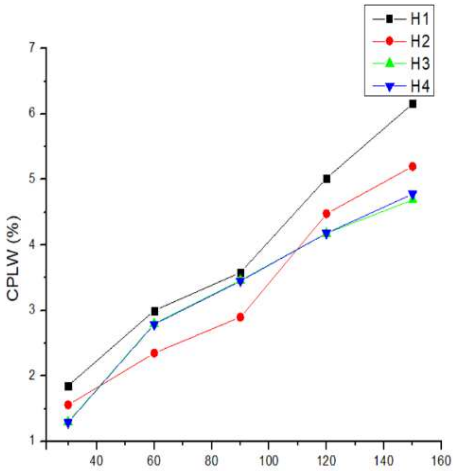


Storage period under refrigerated conditions (days)

(j)

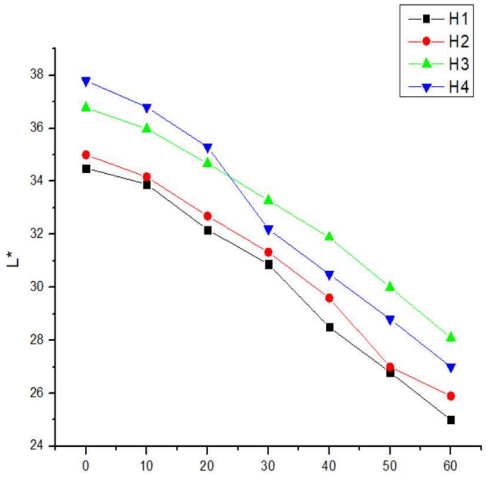


Storage period under ambient conditions (days)

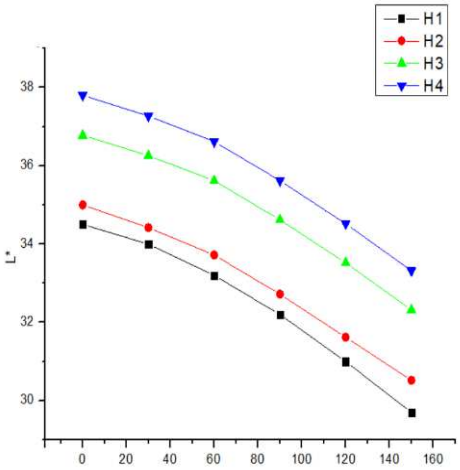


Storage period under refrigerated conditions (days)

(k)

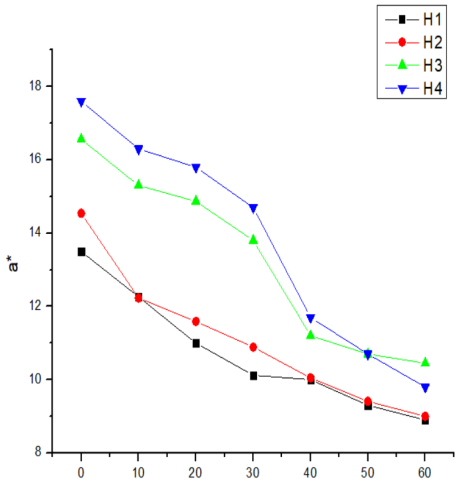


Storage period under ambient conditions (days)

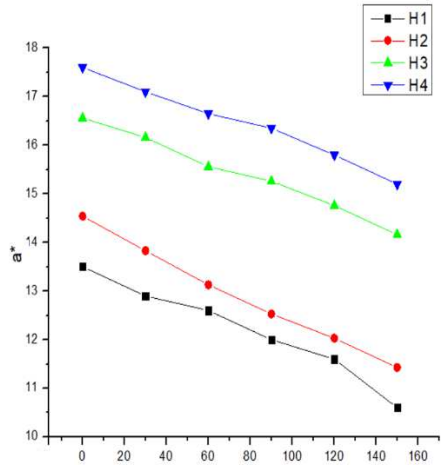


Storage period under refrigerated conditions (days)

(l)



Storage period under ambient conditions (days)



Storage period under refrigerated conditions (days)

(m)

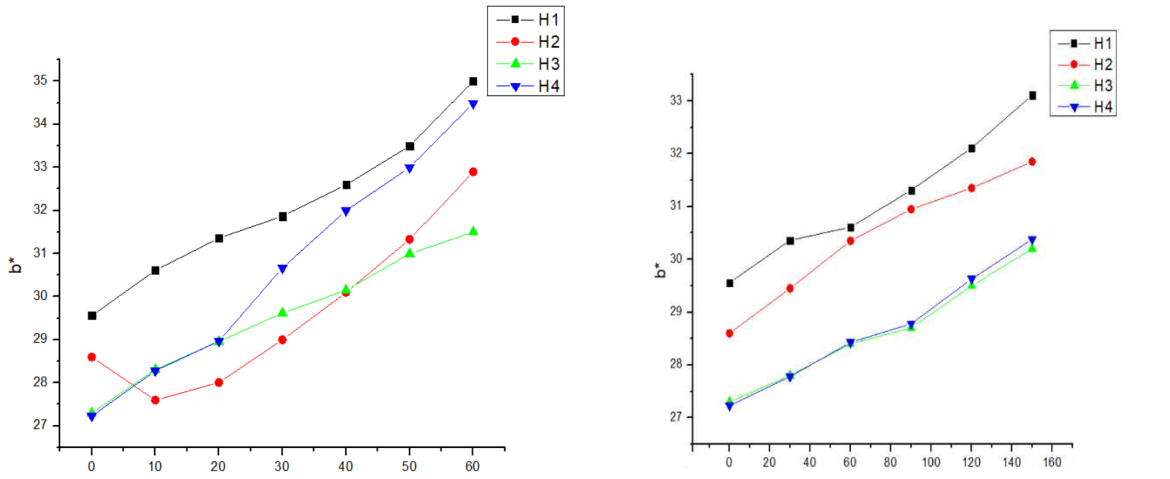


Fig. 1. Effect of harvest maturity (H1–H4) and storage conditions (ambient and refrigerated) on postharvest quality attributes of 'Red Chief' apple: (a) starch–iodine index, (b) firmness, (c) TSS, (d) titratable acidity, (e) total sugars, (f) ascorbic acid, (g) pectin, (h) anthocyanins, (i) juice content, (j) cumulative physiological loss in weight (CPLW), and (k–m) color parameters (L*, a*, b*).

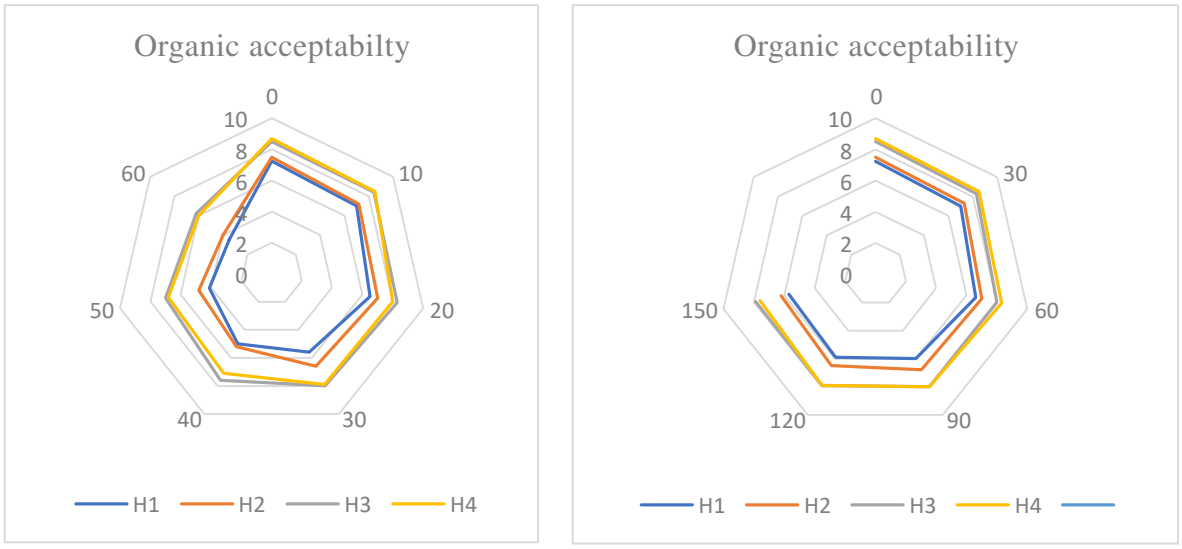


Fig. 2. Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient and refrigerated) on organic acceptability of Red Chief (exotic) apple cultivar

1. AMBIENT STORAGE DATA

Table 1: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on starch-iodine rating, fruit firmness and TSS of Red Chief (exotic) apple cultivar

Harvests / Storage	Starch-iodine rating (1-6 scale)					Fruit firmness (Ibs)					TSS (^{0}Brix)				
	H1	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	2.00	2.70	3.50	4.70	3.23	17.94	16.10	15.94	14.80	16.20	10.15	10.57	11.39	12.03	11.04
10 DAS	3.00	3.50	5.20	5.70	4.35	16.60	16.00	14.98	13.12	15.18	10.55	10.87	11.59	12.23	11.31
20 DAS	6.00	6.00	6.00	6.00	6.00	13.85	13.50	13.20	12.41	13.24	10.85	11.07	11.79	12.43	11.54
30 DAS	6.00	6.00	6.00	6.00	6.00	11.13	11.00	11.20	11.00	11.08	11.15	11.37	11.97	12.63	11.78
40 DAS	6.00	6.00	6.00	6.00	6.00	10.01	10.00	10.80	9.80	10.15	11.00	11.30	11.60	12.50	11.60
50 DAS	6.00	6.00	6.00	6.00	6.00	8.30	8.25	10.00	8.20	8.68	10.50	11.01	11.30	12.10	11.22
60 DAS	6.00	6.00	6.00	6.00	6.00	7.02	7.05	8.80	7.00	7.46	10.00	10.80	11.00	11.02	10.70
Mean (H)	5.00	5.17	5.53	5.77		12.13	11.70	12.12	10.90		10.60	10.99	11.52	12.13	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.017 Harvest (H) = 0.017 S × H = 0.033					Storage (S) = 0.167 Harvest (H) = 0.167 S × H = 0.334					Storage (S) = 0.016 Harvest (H) = 0.016 S × H = 0.032				

Table 2: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on acidity, total sugars and ascorbic acid of Red Chief (exotic) apple cultivar

Harvests / Storage	Acidity (%)					Total sugars (%)					Ascorbic acid (mg/100g)				
	H1	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	0.335	0.315	0.290	0.260	0.300	8.62	8.98	9.68	10.22	9.38	7.32	7.50	7.58	7.75	7.54
10 DAS	0.300	0.295	0.265	0.240	0.275	8.96	9.24	9.85	10.39	9.61	6.82	7.00	7.28	7.35	7.11
20 DAS	0.275	0.255	0.245	0.220	0.249	9.22	9.41	10.02	10.56	9.80	6.43	6.50	6.54	6.85	6.58
30 DAS	0.240	0.235	0.225	0.210	0.228	9.47	9.66	10.17	10.74	10.01	5.70	5.90	6.00	6.15	5.94
40 DAS	0.210	0.190	0.160	0.190	0.187	9.20	9.30	10.10	10.60	9.80	5.20	5.50	5.80	6.01	5.62
50 DAS	0.150	0.150	0.130	0.110	0.135	8.50	8.56	9.80	9.84	9.17	5.03	5.10	5.30	5.31	5.18
60 DAS	0.100	0.120	0.115	0.100	0.108	7.00	7.30	9.00	8.90	8.05	4.80	5.00	5.10	5.08	4.99
Mean (H)	0.230	0.222	0.204	0.190		8.71	8.92	9.80	10.17		5.90	6.07	6.22	6.35	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.002 Harvest (H) = 0.002 S × H = 0.003					Storage (S) = 0.017 Harvest (H) = 0.017 S × H = 0.033					Storage (S) = 0.015 Harvest (H) = 0.015 S × H = 0.030				

Table 3: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on pectin, anthocyanin content and juice content of Red Chief (exotic) apple cultivar

Harvests / Storage	Pectin (%)					Anthocyanin (mg/100g)					Juice content (%)				
	H1	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	0.95	0.90	0.83	0.65	0.83	28.10	31.20	34.20	37.40	32.73	63.00	65.20	67.32	65.57	65.27
10 DAS	0.88	0.83	0.74	0.57	0.76	29.80	32.80	35.12	38.20	33.98	61.20	60.53	63.80	59.32	61.21
20 DAS	0.83	0.78	0.68	0.46	0.69	29.10	32.20	34.82	38.00	33.53	51.90	52.00	57.69	57.32	54.73
30 DAS	0.50	0.45	0.44	0.20	0.40	28.90	31.70	34.42	37.70	33.18	45.30	47.10	51.70	43.10	46.80
40 DAS	0.40	0.36	0.36	0.13	0.31	28.50	31.55	34.35	37.61	33.00	40.25	46.00	47.56	38.50	43.07
50 DAS	0.31	0.25	0.26	0.10	0.23	28.00	31.08	34.00	36.90	32.49	33.10	40.89	45.52	36.01	38.88
60 DAS	0.10	0.12	0.19	0.08	0.12	27.30	29.11	33.50	35.68	31.39	26.90	33.63	40.02	32.51	33.26
Mean (H)	0.57	0.53	0.50	0.31		28.52	31.37	34.34	37.35		45.95	49.33	53.37	47.47	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.015 Harvest (H) = 0.015 S × H = 0.030					Storage (S) = 0.145 Harvest (H) = 0.145 S × H = 0.289					Storage (S) = 0.017 Harvest (H) = 0.017 S × H = 0.035				

Table 4: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on CPLW of Red Chief (exotic) apple cultivar

Harvests / Storage	CPLW (%)				
	H1	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	---	---	---	---	---
10 DAS	1.41	2.08	3.17	3.20	2.47
20 DAS	4.53	5.12	3.84	3.94	4.36
30 DAS	9.46	6.21	4.76	5.00	6.36
40 DAS	10.30	7.42	5.70	5.90	7.33
50 DAS	11.12	8.98	7.10	7.50	8.68
60 DAS	13.10	9.90	8.90	10.24	10.54
Mean (H)	9.59	7.41	6.16	6.67	
C.D (P ≤ 0.05)					
Storage (S) = 0.145 Harvest (H) = 0.145 S × H =0.289					

Table 5: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on L*, a* and b* values of Red Chief (exotic) apple cultivar

Harvests / Storage	L*					a*					b*				
	H1	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	34.50	35.00	36.78	37.80	3.23	13.50	14.54	16.56	17.60	16.20	29.56	28.60	27.30	27.23	11.04
10 DAS	33.89	34.17	35.98	36.80	4.35	12.26	12.23	15.30	16.30	15.18	30.61	27.60	28.31	28.28	11.31
20 DAS	32.18	32.69	34.68	35.30	6.00	11.00	11.59	14.87	15.80	13.24	31.36	28.01	28.96	28.97	11.54
30 DAS	30.88	31.33	33.28	32.20	6.00	10.12	10.89	13.80	14.70	11.08	31.87	29.00	29.62	30.67	11.78
40 DAS	28.50	29.60	31.89	30.50	6.00	10.00	10.05	11.20	11.70		32.60	30.10	30.15	32.00	
50 DAS	26.80	27.00	30.00	28.80	6.00	9.30	9.41	10.70	10.70		33.50	31.33	31.00	33.00	
60 DAS	25.00	25.90	28.10	27.00		8.90	9.00	10.45	9.80		35.00	32.90	31.50	34.49	
Mean (H)	5.17	5.32	5.50	5.78							10.15	10.57	11.39	12.03	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.170 Harvest (H) = 0.170 S × H = 0.341					Storage (S) = 0.168 Harvest (H) = 0.168 S × H = 0.336					Storage (S) = 0.167 Harvest (H) = 0.167 S × H = 0.334				

Table 6: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (ambient) on organic acceptability (1-9 hedonic scale)* of Red Chief (exotic) apple cultivar

Harvests / **Storage**	H1	H2	H3	H4
0	7.24	7.50	8.50	8.70
10	7.00	7.20	8.42	8.50
20	6.50	7.00	8.30	8.00
30	5.60	6.60	8.00	7.90
40	5.00	5.20	7.60	7.10
50	4.10	4.80	7.00	6.80
60	3.50	4.00	6.20	6.00

***9 =Like Extremely, 8 = Like Very Much, 7 = Like Moderately, 6 = Like Slightly, 5 = Neither like nor dislike, 4= Dislike Slightly, 3 =Dislike Moderately, 2 = Dislike Very Much and 1= Dislike extremely**

REFRIGERATED STORAGE DATA

Table 7: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on starch-iodine rating, fruit firmness and TSS of Red Chief (exotic) apple cultivar

Harvests / Storage	Starch-iodine rating (1-6 scale)					Fruit firmness (Ibs)					TSS (^{0}Brix)				
	H1	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**	**H1**	**H2**	**H3**	**H4**	**Mean (S)**
0 DAS	2.00	2.70	3.50	4.70	3.23	17.94	16.10	15.94	14.80	16.20	10.15	10.57	11.39	12.03	11.04
30 DAS	5.00	5.20	5.50	6.00	5.43	16.89	15.17	14.45	13.02	14.88	10.45	10.97	11.59	12.23	11.31
60 DAS	6.00	6.00	6.00	6.00	6.00	14.92	13.80	12.32	11.97	13.25	10.75	11.37	11.69	12.43	11.56
90 DAS	6.00	6.00	6.00	6.00	6.00	12.12	11.86	10.82	10.70	11.38	10.65	11.27	11.59	12.33	11.46
120 DAS	6.00	6.00	6.00	6.00	6.00	10.52	10.30	10.02	09.90	10.19	10.45	11.07	11.49	12.23	11.31
150 DAS	6.00	6.00	6.00	6.00	6.00	09.35	09.30	09.50	09.20	9.34	10.35	10.87	11.42	12.07	11.18
Mean (H)	5.17	5.32	5.50	5.78		13.62	12.76	12.18	11.60		10.48	11.02	11.53	12.27	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.016 Harvest (H) = 0.013 S × H = 0.033					Storage (S) = 0.165 Harvest (H) = 0.134 S × H = 0.329					Storage (S) = 0.082 Harvest (H) = 0.067 S × H = 0.163				

Table 8: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on acidity, total sugars and ascorbic acid of Red Chief (exotic) apple cultivar

Harvests / Storage	Acidity (%)					Total sugars (%)					Ascorbic acid (mg/100g)				
	H_1	H_2	H_3	H_4	Mean (S)	H_1	H_2	H_3	H_4	Mean (S)	H_1	H_2	H_3	H_4	Mean (S)
0 DAS	0.335	0.315	0.290	0.260	0.300	8.63	8.98	9.68	10.23	9.38	7.32	7.50	7.58	7.75	7.54
30 DAS	0.305	0.295	0.275	0.250	0.281	8.88	9.32	9.85	10.40	9.61	6.76	6.93	7.00	7.18	6.97
60 DAS	0.280	0.270	0.265	0.235	0.263	9.14	9.66	9.94	10.57	9.83	6.29	6.20	6.44	6.61	6.39
90 DAS	0.253	0.250	0.250	0.225	0.245	9.05	9.58	9.85	10.48	9.74	5.21	5.26	5.36	5.47	5.33
120 DAS	0.235	0.245	0.240	0.210	0.233	8.88	9.40	9.77	10.40	9.61	4.00	5.01	5.04	5.06	4.78
150 DAS	0.220	0.240	0.235	0.195	0.223	8.79	9.23	9.70	10.26	9.50	3.00	3.01	3.02	3.02	3.01
Mean (H)	0.272	0.269	0.259	0.229		8.90	9.36	9.80	10.39		5.43	5.65	5.74	5.85	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.002 Harvest (H) = 0.001 S × H = 0.003					Storage (S) = 0.017 Harvest (H) = 0.013 S × H = 0.033					Storage (S) = 0.016 Harvest (H) = 0.013 S × H = 0.033				

Table 9: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on pectin, anthocyanin content and juice content of Red Chief (exotic) apple cultivar

Harvests / Storage	Pectin (%)					Anthocyanin content (mg/100g)					Juice Content (%)				
	H_1	**H_2**	**H_3**	**H_4**	**Mean (S)**	**H_1**	**H_2**	**H_3**	**H_4**	**Mean (S)**	**H_1**	**H_2**	**H_3**	**H_4**	**Mean (S)**
0 DAS	0.95	0.90	0.83	0.65	0.83	28.10	31.20	34.20	37.40	32.73	63.00	65.20	67.32	65.57	65.27
30 DAS	0.88	0.87	0.82	0.63	0.80	28.60	31.60	34.55	37.70	33.11	61.00	64.10	66.00	63.12	63.56
60 DAS	0.85	0.84	0.79	0.59	0.78	28.00	31.10	34.10	37.30	32.63	58.60	62.00	64.01	61.00	61.40
90 DAS	0.80	0.78	0.77	0.55	0.73	26.50	30.10	33.15	36.40	31.54	56.50	60.03	62.20	58.80	59.38
120 DAS	0.60	0.58	0.45	0.30	0.51	26.30	30.00	33.10	35.68	31.27	54.45	58.00	59.90	56.67	57.26
150 DAS	0.34	0.30	0.27	0.12	0.26	26.00	28.80	32.95	35.55	30.83	50.20	53.02	56.50	54.40	53.53
Mean (H)	0.74	0.71	0.67	0.47		27.25	30.47	33.68	36.67		57.29	60.39	62.66	59.93	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.018 Harvest (H) = 0.013 S × H = 0.031					Storage (S) = 0.165 Harvest (H) = 0.134 S × H = 0.329					Storage (S) = 0.412 Harvest (H) = 0.336 S × H = 0.823				

Table 10: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on CPLW of Red Chief (exotic) apple cultivar

Harvests / Storage	CPLW (%)				
	H_1	**H_2**	**H_3**	**H_4**	**Mean (S)**
0 DAS	---	---	---	---	---
30 DAS	1.85	1.56	1.30	1.29	1.50
60 DAS	3.00	2.35	2.80	2.79	2.74
90 DAS	3.58	2.90	3.46	3.45	3.35
120 DAS	5.02	4.48	4.18	4.18	4.47
150 DAS	6.16	5.20	4.69	4.78	5.21
Mean (H)	3.27	2.75	2.74	2.75	
C.D ($P \leq 0.05$)					
Storage (S) = 0.151 Harvest (H) = 0.123 S × H =0.302					

Table 11: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on L*, a* and b* values of Red Chief (exotic) apple cultivar

Harvests / Storage	*L**					*a**					*b**				
	H_1	**H_2**	**H_3**	**H_4**	**Mean (S)**	**H_1**	**H_2**	**H_3**	**H_4**	**Mean (S)**	**H_1**	**H_2**	**H_3**	**H_4**	**Mean (S)**
0 DAS	34.50	35.00	36.78	37.80	36.02	13.50	14.54	16.56	17.60	15.55	29.56	28.60	27.30	27.23	28.17
30 DAS	34.00	34.42	36.26	37.27	35.49	12.90	13.83	16.16	17.10	15.00	30.36	29.45	27.80	27.78	28.85
60 DAS	33.20	33.72	35.62	36.62	34.79	12.60	13.13	15.56	16.65	14.49	30.61	30.35	28.40	28.43	29.45
90 DAS	32.20	32.72	34.62	35.62	33.79	12.00	12.53	15.26	16.35	14.04	31.31	30.95	28.70	28.78	29.94
120 DAS	31.00	31.62	33.52	34.52	32.67	11.60	12.03	14.76	15.80	13.55	32.11	31.35	29.50	29.63	30.65
150 DAS	29.70	30.52	32.32	33.32	31.46	10.60	11.43	14.16	15.20	12.85	33.11	31.85	30.20	30.38	31.39
Mean (H)	32.43	33.00	34.85	35.86		12.20	12.92	15.41	16.45		31.18	30.43	28.65	28.71	
C.D ($P \leq 0.05$)															
	Storage (S) = 0.160 Harvest (H) = 0.146 S × H = 0.340					Storage (S) = 0.164 Harvest (H) = 0.134 S × H = 0.329					Storage (S) = 0.165 Harvest (H) = 0.134 S × H = 0.330				

Table 12: Effect of harvest dates (H1= First harvest, H2= Second harvest, H3= Third harvest, and H4= Fourth harvest) and storage conditions (refrigerated) on organic acceptability (1-9 hedonic scale)* of Red Chief (exotic) apple cultivar

Harvests / **Storage**	H1	H2	H3	H4
0	7.24	7.50	8.50	8.70
30	7.00	7.30	8.30	8.50
60	6.60	7.00	8.00	8.30
90	6.00	6.80	7.99	8.00
120	5.90	6.50	7.90	7.90
150	5.70	6.21	7.88	7.60

***9 =Like Extremely, 8 = Like Very Much, 7 = Like Moderately, 6 = Like Slightly, 5 = Neither like nor dislike, 4= Dislike Slightly, 3 =Dislike Moderately, 2 = Dislike Very Much and 1= Dislike extremely**