International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8, 2025
https://www.theaspd.com/ijes.php

# Comparative Analysis Of Firmness And Tss Levels In Royal Delicious And Red Gold Apples Under Varying Storage Conditions

**Uppal Chandra Ratcha[1*], KV Narasimha Rao[2], Ramesh Babu Damarla[3], P.S.N. Masthan Vali[4], Manjula Gandhi S[5]**
[1,2,4] Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Andhra Pradesh, India-522302
[3] School of Business, SR University, Warangal, Indi-506371
[5]Department of Computing, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India-641014
Email: uppalchandraratcha@gmail.com[1*], drkvnrao@kluniversity.in[2], rameshdamarla2009@gmail.com[3], sivanagamastanvali@gmail.com[4], manjulagandhi@cit.edu.in[5]

***Abstract***
*The post-harvest quality of apples significantly influences their marketability, consumer preference and overall economic value. This study examined the effects of Total soluble solids (TSS) and firmness in two apple cultivars, Royal Delicious and Red Gold, under different storage conditions to determine the best storage environment. Apples were stored at room temperature and controlled temperature (10-15°C) for 10 days, with daily measurements of firmness and TSS levels. Two-way ANOVA analysis showed a significant decrease in firmness over time for both varieties. However, Red Gold retained firmness better, particularly under controlled conditions. Royal Delicious consistently exhibited higher TSS values than Red Gold across all storage conditions, indicating greater sweetness. The findings suggest that Red Gold is better suited for long-term storage due to its superior firmness retention, whereas Royal Delicious, with its higher TSS levels, is more desirable for immediate consumption. The study highlights the importance of controlled temperature storage in reducing firmness loss, extending shelf life, and preserving apple quality. These insights can assist apple producers, storage managers, and retailers in optimizing storage and marketing strategies for different apple cultivars. Further research on extended storage periods, biochemical parameters, and genetic factors is necessary for improved post-harvest management.*
***Keywords:*** *Apple storage; firmness; total soluble solids; post-harvest quality; Royal Delicious; Red Gold; controlled temperature storage*

## 1. INTRODUCTION

Impact of postharvest Handling and Storage on Apple Firmness in India was done by Ramesh Babu and Narasimha Rao [1]. They conducted experiment on apples firm after they are picked, especially those grown in India. Firmness is important for people who eat apples. This work talks about how things like temperature, humidity, and how apples are handled can change their texture. It says that enough data is not available about how long to keep apples and why Indian apples get less firm. The authors reported that better places are necessary to keep apples cool and better ways to move them around to keep them fresh. They also compared Indian apples to those from other countries and stated that where they are grown can change their texture. Finally, the paper suggests doing more research to improve how apples are stored and handled, which will help farmers and people who eat apples.

Simulation of cooling Behaviour in Bananas Ripening in cold storage was conducted by Narasimha Rao et al. [2]. The bananas were cooled down before starting the ripening process. The temperature was reduced from 29°C to 19°C using a refrigerator. Once the desired temperature was reached, ethylene gas was added at a rate of 100 parts per million (ppm) for 5 metric tons of bananas. It took about 6 hours to cool the bananas. The cooling process was studied using three types of linear, exponential, and second-order polynomial (quadratic) equations. Among these, the second-order polynomial model matched the actual cooling data the best, with a high accuracy ($R^2$ = 0.939). The results suggest that this method can help design better refrigeration systems and improve the timing of ethylene gas use for different amounts of bananas in future experiments.

Analysing mango fruit temperature gradients mathematically under unstable phase cooling was done by Narasimha Rao et al. [3]. How mangoes cool down during artificial ripening in a cold chamber. They tested three different quantities of mangoes: 4, 6, and 10 metric tons (MT). The mangoes were ripened using ethylene gas in a sealed chamber. It took 16 hours for 4 MT, 20 hours for 6 MT, and 26 hours for 10 MT to reach a steady cooling state. The cooling rates were analysed using three types of mathematical models: linear, exponential, and polynomial. The exponential model gave the best results for 4 MT and 6 MT, with accuracy values ($R^2$) of 0.978 and 0.971. For the 10 MT batchWith an R2 value of 0.994, the second-order type linear equation proved to be the one with the greatest precision.

Handling of Apples During Sorting and Its Effect on Firmness properties were Discussed experimentally by Babu DR et al. [4]. Investigated how different sorting methods affect the firmness of apples after storage. The study found that using water-based systems for sorting significantly reduced mechanical damage compared to manual handling. Apples handled with water retained up to 15–20% more firmness after two months in controlled atmosphere storage. This method proved effective across multiple apple varieties. The authors recommend adopting gentle, water-based handling techniques and further exploring water cooling methods to improve postharvest quality and extend shelf life.

Physical deformation characteristics of apple fruit inaccuracies in penetrometer observations were experimentally conducted by Ramesh Babu D et al. [5]. Found how to evaluate the firmness of apples more accurately. It compared using a handheld penetrometer with using the same device mounted on mechanical evaluation equipment. The findings indicated that using the penetrometer with a stand gave more reliable and consistent readings by reducing human error. While advanced tools like texture analyzers are more precise, they are expensive and not practical for everyday use in farms or storage units. The study recommends using the FT327 penetrometer with a stand as a simple and effective method for checking apple firmness in postharvest quality control.

DR BABU et al. [6]. studied experimentally On Mathematical Modelling of Frying Dynamics in Onion Slices. They found that when onions are fried at high temperatures, they lose moisture and absorb the oil faster. Drying onions before roasting them can help absorb less oil. The onion changes colour during roasting, darkening at first and then fading.

Modelling Temperature Changes in Fruits During the Unsteady Cooling in cold storage was conducted by Raghava KD et al. [7]. The main aims of this study were to model how fruit temperatures drop from 25°C to 5°C during the initial cooling phase in cold storage. Two experiments were conducted using 50 MT and 100 MT of fruits stored in perforated crates under 90–95% relative humidity. Temperature data was recorded using a Plant Visor Pro data logger in a 120 TR capacity cold chamber. The cooling tendency was analysed using three statistical approaches: exponential, second order, and third-order polynomials. The model of third-order polynomials best fit the 50 MT data ($R^2 = 0.998$), while the second-order polynomial model was most accurate for 100 MT ($R^2 = 0.995$). Steady-state temperatures were reached in 21 hours for 50 MT and 34 hours for 100 MT were observed. The future work that can be conducted based on this experiment is by varying the sizes, packing materials and the air flow rate in the chamber to optimum values of preservation life of fruit preservation and improve refrigeration system design.

The banana, mango and citrus fruits healthy ripen and the design details of refrigeration systems are given based on experimental investigations by D. Ramesh Babu et al. [8]. They ripen fruits without calcium carbide or by any other harmful chemicals. The industrial setup for the refrigeration system for the storage of fruits, the insulations and the ethylene ripening equipment details were clearly known by this research to ripe the fruits safely.

Viscoelastic Behaviour of Alginate texturized Muskmelon Pulp was done by Babu DR et al. [9]. They investigated how adding alginate affects the texture of muskmelon (cantaloupe) pulp. The results showed that alginate significantly improved the pulp's firmness and stability, giving it a more gel-like, elastic texture. As temperature increased, the stiffness of the alginate-treated pulp also increased, indicating enhanced structural integrity. These findings suggest that alginate can be effectively used to modify the texture of fruit pulps, making them more suitable for processed food applications such as gels, desserts, or fruit-based snacks.

Babu DR et al. [10]. Explained the Rheological characteristics of muskmelon (cantaloupe) pulp. The study evaluated the flow behaviours of musk pulp. It was found to follow the typical pattern of "pseudoplasticity with yielding stress." This means that the solution will not flow easily unless a certain amount of force is applied. The researchers used various statistical models to explain this behaviour and found that the Herschel-Bulkley model fit the data best. They also measure how the flow rate changes at different temperatures.

Safe Working Conditions in Low Oxygen Cold Storage Units was done by Kolati SB et al. [11]. Controlled atmosphere (CA) storage is a new technology in India that helps keep fruits and vegetables fresher for longer. However, due to poor ventilation, entering confined spaces can be dangerous for workers. The aim of this investigation was to determine the ways to prevent accidents and protect workers who may accidentally enter the building.

The pressure Resistance in CAS Insulated Enclosures was conducted experimentally and mathematically by Deshmukh Ret al. [12]. This is the first Indian study on pressure testing of semi-hermetically sealed Controlled Atmosphere Storage (CAS) enclosed spaces, combining experimental and mathematical approaches. These chambers are designed to maintain small amounts of oxygen and elevated amount of carbon dioxide are used to decrease transpiration and breathing rates in fruits, especially apples. Constructed using Polyurethane Foam and sealed with Ribbstyle Elastic paint, the chambers were tested for pressure drop using an air blower, with reference standards from ISO 6949. Three chambers of varying volumes showed different pressure drop rates. Two mathematical models, exponential and second-order polynomial—were used to analyse the data, with the polynomial model providing the best fit. The study highlights the importance of chamber volume in pressure retention and suggests future research into CAS chambers operating at high, low, and ultra-low oxygen levels for optimized apple storage.

Kassebi S et al. [13]. was Investigated on the shelf-life behaviour of golden Delicious Apples. The apples are kept at ambient temperature. (24°C, 60% RH) over six weeks by monitoring Total Soluble Solids (TSS), weight loss, and colorimetric changes. Using a portable colour sensor, the research tracks chroma and ΔE values, which increased over time, indicating darker and more saturated apple skin. Colour changes followed an exponential regression, while TSS and weight loss exhibited linear trends. These patterns helped identify saturation points in quality parameters, offering insights into the late-stage shelf-life of apples. The study introduces a non-destructive, consumer-friendly method to assess apple freshness based on visual cues, enabling better purchasing decisions. By correlating visual and physical quality indicators, it provides a practical approach to evaluating fruit degradation and optimizing storage or marketing strategies.

Apple Quality Changes During Storage had studied experimentally by Ahmad F et al. [14]. The evaluated apples' firmness, total soluble solids (TSS), acidity, density, qualities of shades, lustre, among other physical and chemical quality characteristics, while they were being stored. Based on these characteristics, the overall quality index (OQi) models were created. TSS varied from 14.1% to 12.7%, acidity from 0.163% to 0.081%, and firmness from 11.88 to 7.68 N. Hunter's colour values ranged from 24.20 to 30.12 for a, 51.75 to 57.01 for L, and 19.53 to 22.96 for b. There is a possibility for non-destructive OQi prediction using features during storage, since the OQi, which was obtained from a developed model (ML2), showed a strong correlation with sensory scores.

Ding X et al. [15]. Studied on Comparing the Softness and Storage Quality of Different Apples. The The fruit preservation and structure characteristics of four apple varieties—Orin, RX, RXH, and Envy—were examined in this study. The study concentrated on the physiological markers of respiration, ethylene generation, amylase activity, and cell wall composition as well as other parameters that affect post-harvest softeningSubsequent softening was linked to more exercise of cellulose (CEL), water-soluble pectin (WSP), and other hydrolases, However, higher respiration and amylase action were linked to the beginning softening. Fruit cells grew looser during storage, resulting in wider intercellular spaces. Differences in texture between apple cultivars were caused by Changes in Mdβ-gal opinion, cellulose concentration, CEL movement, and WSP.

How Climate Affects Ripening in Two Regions was Investigated by Molina-Corral FJ et al. [16]. The Gold Delectable and fiery Chihuahua, Mexico (CHIH) and Washington, USA (WA) produced some delicious apples that compared in quality over the course of three years. Each week, apples were picked, and their quality characteristics examined. CHIH apples took three more weeks to ripen, perhaps because of their higher elevation, while WA apples displayed a five-week bloom delay because of lower temperatures. The main distinctions were that CHIH apples had more volatile chemicals that gave them a stronger scent and WA apples were firmer. Temperature and light may have an impact on firmness, as seen by the substantial correlation (R=0.89) between firmness and photothermal units.

Improving Apples Shelf Life with Natural Aloe Vera Coating was conducted by Malik MR et al. [17]. The effects of varying Aloe vera (ALV) coatings (0%, 5%, 10%, and 15%) on apples stored at room temperature for 40 days were evaluated in a study conducted at Baluchistan Agriculture College in Quetta. The findings indicated that 15% ALV (T4) enhanced firmness (9.43 N), flavour, and marketability while considerably improving fruit quality, lowering weight loss (11%), decay (1.30%), and illness incidence (2.1). T4 also maintained an appropriate TSS/TA ratio, greater EC, and a lower ph. Therefore, 15% ALV successfully increased apple shelf life and decreased spoiling.

Lu L et al. [18]. Studied on Comparing Meihong and Golden Apples After Harvest. In this investigation, Meihong and Golden Delicious apples were kept at room temperature, low temperature, and low temperature with 1-MCP after harvest. "Meihong" performed superior in terms of storage potential and ethylene release. Preserved flavonoids and anthocyanins, delayed softening, decreased ethylene and ester aroma release, and Lower temperatures, particularly with 1- MCP. They were ACS1-1/-2 heterozygotes, both cultivars. Overall, "Meihong" apple quality was successfully preserved by low temperature with 1-MCP, indicating its potential for better postharvest storage and longer shelf life.

Comparing Apple Freshness After DCA, CA and 1-MCP Treatments was investigated by Shi M et al. [19]. Postharvest quality is vital in the fiercely competitive apple industry. Product rejection in markets with high standards can result from poor quality, which also lowers demand. Apple quality was examined in this review in relation to the impacts of Dynamic Controlled Atmosphere (DCA), CA with 1-MCP, and Controlled Atmosphere (CA). CA exhibited the lowest firmness, whilst DCA was the best in preventing internal browning and water core after six months. According to sensory assessments, DCA and CA+1-MCP produced comparable outcomes. Although cultivar-specific reactions must be considered, DCA presents a possible substitute, particularly for organic apples.

Rojas-Candelas et al. [20]. I studied Predicting Apple Texture Using Nanoindentation and Cell Wall Properties. To discover essential parameters determining its texture, this research investigated the physicochemical, fundamental, and nanomechanical qualities of four apple varieties. The use of microscopes, spectroscopy, The use of indents of nanoparticles, and statistical modelling (PCA, Pearson analysis, multiple regression) are utilized. A model used for prediction ($R^2$ = 0.97) revealed that rigidity is highly influenced by cellular architecture, cell wall stiffness, and cellulose crystallinity value. The outcomes provide useful information on the multiscale elements that influence the apple surface.

Comparing Fuji and Hanfu Apples After Cold 1-MCP Maintaining was Investigated by Gao Q et al. [21]. the storage potential of Fuji and Hanfu Apples in fresh, cold, and 1-MCP treated settings. 'Hanfu' apples have much greater vitamin C levels than 'Fuji' apples, allowing cultivar differentiation. Fresh and preserved 'Fuji' had greater texture, although 'Hanfu' had a better scent after storage. 1-MCP increased 'Hanfu' quality but had no influence on 'Fuji'. PCA and OPLS-DA are effectively distinguished between cultivars. Overall, 1-MCP treatment shows promise in improving the postharvest quality of 'Hanfu' apples.

Improving Shalimar Apple Storage with Controlled Atmospheres was Conducted by Khera K et al. [22]. The controlled atmosphere (CA)at $1^0$C is recommended for the long haul preservation of Shalimar apples in this study's evaluation of storage methods, even though it may alter scent. In addition to 1-MCP improving stiffness, DCA-CD better retains volatiles. PCA helped to optimize high-quality, sustainable storage options for this cultivar by revealing important correlations.

Studying the Apple Shelf Life Through Weight, Colour, and TSS had studied experimentally done by Kassebi S et al. [23]. On the post-harvest alterations in Golden Delicious apples kept at room temperature (24°C, 60% humidity) for six weeks are examined in this study. It looks at colour change, reduction in body weight and total soluble solids (TSS), all of which have an impact on shelf life and consumer appeal. A refractometer was used to measure TSS, a colorimeter to detect colour changes, and a high-precision scale to monitor weight loss. The study discovered a substantial relationship between TSS and the other factors as well as a high correlation between colour shift and weight loss. These realisations can promote sustainable food systems, lessen spoiling, and enhance storage procedures.

Ding X and Zheng Y conducted experiments [24]; they produced how apple types of quality and shelf life are impacted by their post-harvest softening. Apple varieties 'Orin', 'RX', 'RXH', and 'Envy' were examined. Elevated oxygen consumption, ethylene generation, and amylase activity originally served as the causes of softening. Water-soluble pectin, cellulose, and other enzymes were later found to have increased activity in response to it. Larger gaps were produced when apple cells have become more randomly organised gradually. These variations in texture are explained by variations in gene transcription and enzyme activity.
Modelling Postharvest Quality of Apples During Ambient Storage Using Physicochemical Indicators was conducted by Ahmad F and Zaidi S et al. [25]. The study assessed the apples' chemical and physical characteristics while they were being stored following harvest. It developed algorithms to forecast overall quality based on characteristics like density, hardness, pH level, and total soluble solids. Additionally, gloss and colour values were evaluated. Sensory reports served to check the simulations, demonstrating that the projected efficiency scale agreed with the sensory results. The best model estimated quality based on colour, hardness, and acidity values. The study discovered that these measurable qualities might be used to forecast quality in a non-destructive manner.
Comparing Apple Varieties Using Texture and Nutritional Quality was conducted experimentally and analysed by Mureşan AE and Sestras AF et al. [26]. To assess fruit's nutritional characteristics, the analysis was looked at 22 apple varieties out of a total of 600. There were minor variations amongst the varieties, with a standard water content of 85.05%, ash content of 2.32%, and total soluble solids of 16.22%. On the other hand, fruit weight, volume, and acidity varied greatly. Toughness ranged in removed hardness from 3.80 to 13.69 N, core hardness from 0.97 to 4.76N, and thickness from 0.2to 1.07 mm. The research demonstrates how multivariate analyses may evaluate correlations between apple genetic resources and aids in the selection of apple varieties for breeding purposes.
Doe JW et al. [27]. Explained about the How Storage and Tree age Affect Browning in Rosy Glow Apples. Like its parent 'Cripps' Pink,' the 'Rosy Glow' apples were studied for internal flesh browning (IFB). Investigations were conducted into variables like temperature at storage, mineral nutrition, tree age, and harvest maturity, and chemical treatments (1-MCP and DPA). Apples were preserved under supervision after being collected at varying stages of starch breakdown. The findings indicated that 1-MCP therapy decreased IFB incidence, and that appropriate harvest maturity decreased IFB. The most prevalent kind of browning that was seen was diffuse browning. IFB development was impacted by orchard conditions, and compared to 2$^{o}$ C, fruit quality was higher at -0.5$^{o}$ C. More investigation is required.
Grouping Apple Varieties by Taste, Texture, and Use in Food Products were Observed by Zhang M et al. [28]. to determine whether the physicochemical the sensory attributes of fifteen different types of apples, the study looked at them. Peel colour, acidity, amount of sugar, and fragrance components all showed significant variations. Diverse likes towards refined foods were revealed via sensory testing. Three clusters were formed from the apples: Cluster I products (such Royal Gala and Red Delicious) were aesthetically pleasing and Odor-free, making them fit for immediate ingestion. Cluster II (Sinike, Honglu, etc.) had high acidity and sugar content, preparing them for immediate utilization. Cluster III, which included Honey Crisp and Shandong Fuji, was good for fresh-cut apples but had a bad look. These discrepancies were distinguished with the aid of chemometric analysis.
Bound SA et al. [29]. Studied the Target Crop Load Determination for Quality and Yield Balance in Apples. The research investigation looked at how crop load and thinning times affected apple fruit quality and size. Fruit size, hardness, and sugar content were all enhanced by premature reduction. 'Delicious' and 'Fuji' apples demonstrated positive correlations between firmness, weight, and sugar concentration. 'Delicious' should have 2-4 fruit per $cm^2$ trunk area, while 'Fuji' should have 4-6 fruit per $cm^2$. 4-6 is preferable because pink lady and Gala can manage up to 8 fruits per $cm^2$, but the quality will be impaired. While 'Braeburn' should have 4 fruits per $cm^2$ for regular bearing and good size, 'Jonagold' remains adequate size and blooms at 8 fruits per $cm^2$.
The Role of Crop Load and Mineral Nutrition in Postharvest Disorders of Scilate was studied by Sidhu RS and Hunt I et al. [30]. To determine how internal flesh browning (IFB) impacts market value, the study examined 'Scilate' apples. Over three seasons, it looked at fruit quality, crop load, and nutrient status. The result of heavy crop loads was biannual bearing patterns. The following variables were predictive of IFB and fruit softening: crop load, fruit weight, firmness, and nutritional ratios. Fruit

softness and nutritional imbalances were linked to radial browning, whereas excessive phosphorus and potassium levels were linked to $CO_2$ injury. For dense-fleshed apples like "Scilate," controlling crop load and nutrient levels is essential to lowering IFB and enhancing fruit quality.

Phytochemical and Physicochemical profiling of Moroccan Apple Varieties was conducted experimentally and analysed by Mohammed K and Saghrouchni H et al. [31]. The analysis was looked at several Moroccan apple types, concentrating upon their physical and chemical features. Juicy (60–71%) and acidic apples with Brix levels above 13°Brix were identified. Although it was not fit for direct ingestion, the Ahjjani variety's high levels of polyphenols and tannins indicated good nutritional quality. The Story cultivar had a high quantity of flavonoids. The most common of all the organic acids was succinic acid. According to these findings, apple varieties that are unfit for human eating can still be used to make other goods and are a great source of bioactive chemicals.

Mota M et al. [32]. studied Balancing Fertilizers Inputs and Crop Load for Quality and Yield in Gala Apples. The consequences of different fertiliser Different degrees of performance, yield, and nutrient status of 'Gala' apples over a four-year period. Five orchards with different NPK levels were fertilised. There were significant relationships between boron and several plant components. The amounts of phosphorus, calcium, and magnesium in leaves were the only nutrients in fruit or leaves that were substantially impacted by fertilisation. Double fertilisation increased the yield of one orchard by 26%, although the outcomes for other orchards varied each year. Fertilisation had less of an impact on fruit size than crop load. Productivity and quality were unaffected by switching from some chemical fertilisers to organic ones.

Exploring Genetic and Phenotypic Variation in Apple varities of North Kashmir was conducted experimentally and analysed by Najar ZH and Kashtwari M et al. [33]. They analysed the chemical and physical properties of 66 apples varieties grown in North Kashmir during a three-year period. Fruits weighing 18.46 g to 233.97 g were produced by Chemura, Lal Ambri, Red Gravenstein, and UOK 104 that were the biggest. The majority were medium-red, globe-shaped apples. For the most part, harvesting happened late. The ranges of pH and total soluble solids were 2.21 to 4.78 and 10.23 to 16.00 °Brix, respectively. The study found three superior unknown genotypes and fourteen well-known genotypes that are beneficial for commercialisation and propagation. Two major clusters were formed from the apples using the analysis of principal components.

Abdel-Sattar M et al. [34]. studied on Optimizing Irrigation Timing for Enhanced Productivity in Annaforples Cultivars. The effects of fall irrigation determent were studied on Anna apple trees that are six years old over the 2018–2019 and 2019–2020 seasons. Determent for 30 or 45 days beginning on October 1st or 10th (T2-T5) and no determent (T1) were the five treatments that were examined. T3 (45 days from October 1st) showed significant improvements in antioxidant material, glucose, blooming, set of fruits, production and firmness. Fruit set, petal fall, and bud burst were the earliest and latest in T1 and T5. Vegetative spurs, fruit size, and leaf nutrients were all greater in the control (T1). The best method for increasing Apple efficiency was T3.

Singh Sidhu Rand Bound SA et al. [35]. Was Conducted an experiment on Fruit quality and storage potential of Â ScilateÂ apples are influenced by harvest ripeness. 'Scilate' apples were used in this research to investigate the effects of varying harvest times on internal flesh browning (IFB), softening (FS), and fruit quality. Apples were gathered in three different time periods: early (187 days after full bloom), mid (194 days), and late (202). Fruit weight, colour, and dry matter were all improved in subsequent harvests, while malic acid (MA) was decreased. Soluble solids (TSS) and firmness were unaltered at harvest, while late harvest stored fruit had higher TSS and juice pH and reduced MA and firmness. In contrast to mid-harvest, FS and IFB were higher in late harvest. Harvesting later enhances certain attributes but raises FS and IFB hazards.

Epigenetic and Molecular Characterization of Bud Sport variants in apples was Investigated by Kumar A and Sharma DP et al. [36]. A popular crop, apples (Malus × domestica Borkh.) are prized for their nutritional content and health advantages. Because of their genetic complexity, protracted juvenile phase, and perennial nature, traditional breeding is difficult. New apple types can be swiftly created by locating and propagating spontaneous mutations, sometimes known as bud sports. Around the world, a lot of mutant cultivars are cultivated, and new variations are frequently overlooked. In addition to discussing

molecular identification and epigenetic control, this work provides an overview of the characteristics and regulation mechanisms of bud sports, such as fruit peel colour, blooming, and ripening timeframes. For those studying apple genetics and genes, it offers useful information.
Sharma RR and Datta SC et al. [37]. Was Conducted an Experiment on Effect of Particle Film Based on Kaolin sprays on pest Management as well as the quality of Delicious Apples. Pests and illnesses, which are frequently managed with environmentally harmful pesticides, cause significant losses in the production of apples. One organic technique that shows promise is particle film technology (PFT). 'Delicious' apples were used in a study conducted in Himachal Pradesh to test the kaolin-based particle film Surround WP®. From 2015 to 2017, 20 trees received five spray treatments year, while 20 trees remained unsprayed as controls. Surround WP® enhanced woolly apple aphids while decreasing pests and diseases. Apples that have been treated showed improvements in colour, hardness, ascorbic acid, calcium, and soluble solids. There was a notable decrease in storage disorders. To produce organic apples, Surround WP® is advised.
Ranjbar S and Ramezanian A et al. [38]. Explained about the consequences of nano-calcium fertilisation prior to harvest on 'Red Delicious' apples were investigated. Apple trees were sprayed five times, separated by two weeks. with calcium chloride and nano-calcium solutions (0, 1.5, and 2.0%) between thirty days prior to maturity and seventy days following bloom. When the fruit was harvested, its weight, density, length, diameter, and other quality characteristics were measured. Fruit quality and quantity were more significantly impacted by nano-calcium than by calcium chloride; 2.0% nano-calcium produced the greatest results. It reduced soluble solids, sugars, and anthocyanins while increasing titratable acidity, phenolic content, antioxidant activity, fibre, and starch. One fertiliser that shows promise is nano-calcium.
Influence of Summer Pruning and Rootstock selection on Nutrient Uptake and Bitter pit control in Apples was experimentally done by Guerra M and Sanz MÁ et al. [39]. The management of nutrients in 'Silver Spur' apples grown on several rootstocks (MM106, M4, M9) between 2019 and 2020 was investigated in this study. Every 21 days between May and September, samples of leaves and fruit were gathered. N, P, K, Ca, Mg, and B nutrient levels were measured. In contrast to Ca and Mg, which first increased in leaves before declining in fruits, N, P, K, and B gradually reduced in both leaves and fruits. Compared to M4 and M9, the MM106 rootstock had increased nutritional levels, indicating that rootstock affects nutrient absorption. Fruit quality and nutrition management are enhanced by an understanding of these patterns.
Together, these results highlight the great need for comparative research on TSS levels and firmness across cultivars and storage circumstances. The current study examined time-related characteristics and presented some hints that may be useful to apple growers and storage managers in terms of best methods for organisation and enhancing fruit quality.

## 2. MATERIALS AND METHODS

### *2.1 Experimental Design*

This experiment was carried out as a complete random design aimed at investigating how different storage conditions and cultivar types can affect the apple firmness and TSS. Two different apple varieties, including Royal Delicious and Red Gold, were evaluated under ambient and controlled temperatures, which range between 10-15 degrees Celsius. Measurements were taken after 10 successive days.

### *2.2 Sampling*

The experiment was conducted for 10 days. In all, 160 apples were used in the activity, of which 80 were Royal Delicious Apples and 80 Red gold apples. Each variety was further divided into two equal parts for both the storage conditions; thus, at Room Temperature, 40 Royal Delicious apples and 40 Red Gold apples and at Controlled Temperature (10-15°C) 40 Royal Delicious apples and 40 Red Gold apples were taken.

### *2.3 Measurements*

**Firmness:** Firmness was measured daily using a penetrometer as shown in Figure 1, equipped with an 11-mm probe. In each apple, the fruit was measured twice on opposing sides, and the average of both readings was recorded. Newtons (N) were used as the unit of measurement.

**Figure 1:** Penetrometer.

**2.4 Total Soluble Solids:**
A digital refractometer was used to test TSS daily, as seen in Figure 2. The juice of each apple was slightly taken out and put on the prism of the refractometer. The reading of TSS for each sample was measured in terms of °Brix.


**Figure 2**: Refractometer.

***2.5 Data Collection Procedure***
Apples were removed from their assigned storage conditions daily for testing. Firmness readings were initially taken; it is the least destructive procedure compared to juice extraction. Later, the extracted juice was used for measuring TSS. Sample processing and measurement procedures were performed carefully to maintain uniformity in sample handling. The Firmness and TSS readings of room Temperature and 10- 15$^0$C were shown in Table 1: Firmness and TSS at room Temperature. Table 2: Firmness and TSS at 10-15$^0$C.

**Table 1:** Firmness and TSS at room Temperature

| **Storage duration (days)** | **Firmness (N)** | | **TSS ($^0$ Brix)** | |
|---|---|---|---|---|
| | Royal Delicious | Red Gold | Royal Delicious | Red Gold |
| 1 | 4.52 | 6.65 | 10.32 | 10.93 |
| 2 | 4.80 | 5.52 | 11.32 | 10.83 |
| 3 | 2.97 | 4.95 | 11.11 | 10.00 |

| | | | | |
|---|---|---|---|---|
| 4 | 4.20 | 5.25 | 10.86 | 10.83 |
| 5 | 2.97 | 5.52 | 11.77 | 10.20 |
| 6 | 2.57 | 4.22 | 13.15 | 9.33 |
| 7 | 3.47 | 3.80 | 10.18 | 10.83 |
| 8 | 2.65 | 3.77 | 12.83 | 10.37 |
| 9 | 3.07 | 2.95 | 10.42 | 11.42 |
| 10 | 3.12 | 3.20 | 11.11 | 9.80 |

**Table 2:** Firmness and TSS at 10-15$^0$C

| **Storage duration (days)** | **Firmness (N)** | | **TSS ($^0$ Brix)** | |
|---|---|---|---|---|
| | Royal Delicious | Red Gold | Royal Delicious | Red Gold |
| 1 | 4.52 | 6.30 | 11.58 | 10.27 |
| 2 | 3.47 | 5.80 | 12.15 | 10.01 |
| 3 | 4.52 | 6.60 | 11.46 | 9.77 |
| 4 | 3.35 | 4.92 | 12.42 | 9.98 |
| 5 | 3.32 | 4.82 | 9.68 | 9.98 |
| 6 | 3.95 | 3.87 | 11.01 | 10.60 |
| 7 | 3.77 | 4.67 | 10.86 | 9.93 |
| 8 | 3.30 | 4.00 | 11.10 | 11.30 |
| 9 | 3.45 | 4.75 | 10.53 | 10.42 |
| 10 | 3.30 | 4.27 | 12.31 | 10.65 |

***2.6 Statistical Analysis***

To investigate the effects of cultivar, storage condition, and their interaction on firmness and TSS levels at the 0.05 level of significance, data analysis was conducted using two-way ANOVA. For all statistical studies, Python programming was used.

## 3. RESULTS AND DISCUSSION

### *3.1 Firmness*

Two-way ANOVA showed significant effects of both cultivar and storage conditions on firmness. The trend for firmness decline was uniform for Royal Delicious under both the room and controlled temperature conditions, according to Figures 3 and 4. Firmness values for Royal Delicious apples fell from 4.52 N to 3.12 N at room temperature and from 4.52 N to 3.30 N under controlled conditions by Day 10, while Red Gold apples showed higher firmness retention, especially under controlled conditions, with a fall in firmness from 6.30 N to 4.27 N over 10 days.

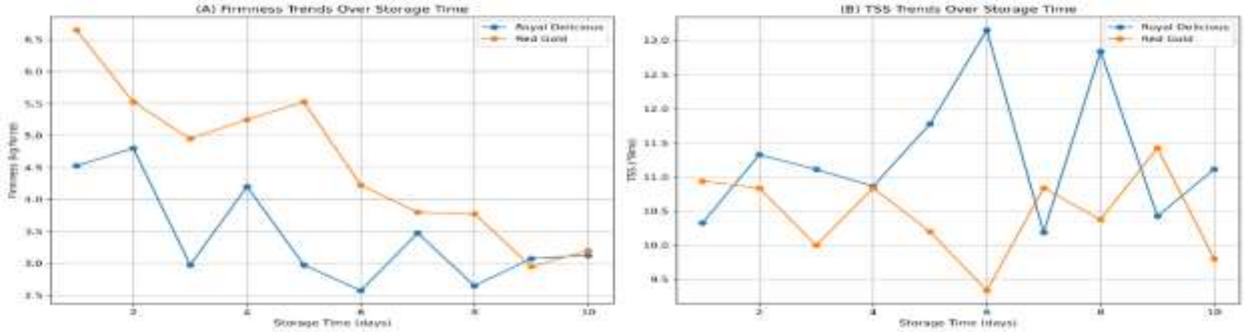

**Figure 3: Firmness and TSS trend at room temperature**

The above figure shows the firmness decline trends of both the cultivars under two storage conditions. It is observable that Red Gold apples had higher values for firmness compared to Royal Delicious apples, hence indicating their suitability for longer storage.

***3.2 TSS***

TSS had a significant main effect of cultivar with no significant effect of the storage condition. Figure 3 and Table 2 present the TSS level in the apple cultivars. Royal Delicious apples consistently had higher TSS levels than Red Gold apples during the experiment. TSS content in Royal Delicious apples stored at room temperature also oscillated between 10.32°Brix and 13.15°Brix, while that of Red Gold apples remained within the range of 10.93°Brix to 11.42°Brix. TSS levels in Royal Delicious apples, under controlled conditions, ranged from 11.58°Brix to 12.31°Brix, while for Red Gold, the variation was minor between 10.27°Brix and 10.65°Brix.

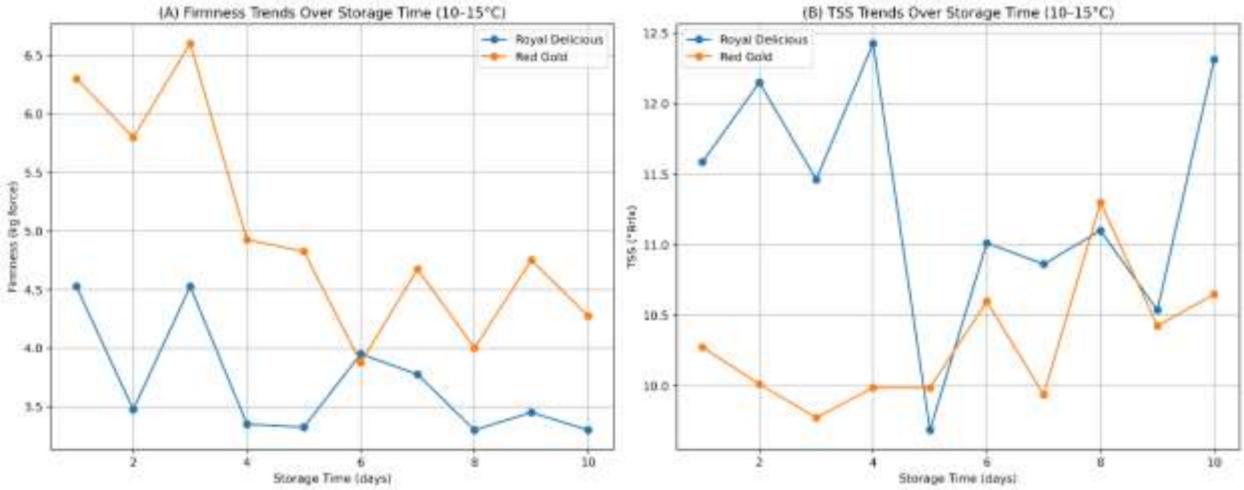


**Figure 4: Firmness and TSS trend at controlled atmosphere (10-15°C)**

The above figure illustrates a trend of TSS during the storage period, it can also be realized by the graph where, even while TSS fluctuates very little, apples of the first variety remain quite ahead and retain their superior attribute of sweetness.

## 3.3 DISCUSSION

The present study investigated the firmness and TSS levels of Royal Delicious and Red Gold apples under two different storage conditions: room temperature (ambient) and controlled temperature (10-15°C). The results provided insightful observations concerning the influence of cultivar type and storage conditions on these crucial quality parameters.

***3.4 Firmness Dynamics in Apple Varieties***

Firmness is among the major factors that determine the quality and consumer preference of apples, as well as the possibility of postharvest storage. The results showed that firmness decreased with time in both varieties, which agrees with previous studies suggesting a gradual loss of firmness because of enzymatic action and cellular degradation When being stored(Sharma et al.) [40]. However, Red Gold apples showed significantly higher retention of firmness compared to Royal Delicious apples, especially under controlled conditions. Red Gold presents higher textural stability as well as suitability for long-time storage.

***3.5 Total Soluble Solids (TSS) Trends***

TSS levels, expressed in °Brix, directly indicate sweetness and the fruit ripening stage. The TSS level was significantly influenced by cultivar type rather than storage circumstances. Throughout the whole time spent in storage and independent of the storage conditions, the apples from the Royal Delicious cultivar showed consistently higher values for TSS when compared with Red Gold apples. This observation aligns with prior research (Babu et al.) [41], that has identified cultivar-specific differences in sugar accumulation and metabolism. The variation in TSS levels suggests that Royal Delicious apples have a higher inherent sugar content, making them preferable for consumers who prioritize sweetness.

This can be elaborated based on continuous metabolic activities that both the cultivars undergo when kept in storage conditions, namely breakdown of starch to sugar, losses of moisture content, and many more. For Royal Delicious apple, at ambient temperature, it ranged between 10.32°Brix and 13.15°Brix whereas under control, it ranged from 11.58°Brix to 12.31°Brix. While TSS values recorded for Red Gold apples showed much more stable boundaries, ranging between 10.93°Brix and 11.42°Brix at room temperature and between 10.27°Brix and 10.65°Brix in controlled conditions, these findings comply with the findings of Sun et al. [42], that different varieties of apples may have different rates of carbohydrate metabolism, thus making them different in their TSS dynamics during storage.

### *3.6 Interaction Between Firmness and TSS*

Interestingly, the study revealed that while firmness consistently declined, TSS levels did not exhibit a clear downward trend. This finding suggests that firmness loss and sugar accumulation do not necessarily follow the same trajectory, supporting the notion that post-harvest biochemical processes such as cell wall breakdown and moisture loss occur independently of sugar metabolism (Jesu et al.) [43]. Greater TSS retention in Royal Delicious further indicates their ability to remain sweet over a period, an issue of major significance regarding marketability and consumer acceptance.

### *3.7 Implications for Post-Harvest Storage Management*

These findings have significant consequences for post-harvest preservation and supply chain management. In this regard, Red Gold was superior in firmness retention and, therefore, more suitable for long-term storage and transportation, especially under controlled temperature conditions. On the other hand, Royal Delicious, due to its higher TSS level, would be more desirable for immediate consumption due to its sweeter taste. These findings suggest that storage strategies should be cultivar-specific, with Red Gold benefiting from extended storage at lower temperatures and Royal Delicious being marketed sooner to maximize their superior TSS levels. Results also point out the importance of controlled storage conditions toward maintaining fruit quality. Observed differences in firmness retention under controlled temperature conditions give further emphasis on proper postharvest management practices using cold storage facilities to minimize deterioration in quality and to extend shelf life.

## 4. CONCLUSION

The present study highlights valuable information on the comparative studies of firmness and TSS levels in Royal Delicious and Red Gold apples as influenced by various storage conditions. It has been reiterated that cultivar type has prime importance regarding the determination of fruit quality attributes with Red Gold apples retaining their firmness more and Royal Delicious apples having higher TSS levels. Moreover, controlled temperature storage reduced the loss of firmness, which is very important in post-harvest management. Further studies can be conducted for longer storage periods and more bio-chemical parameters to better understand the physiology of apple storage. These insights are critical for apple producers, storage facility managers, and retailers who seek to optimize apple quality and market value.

**REFERENCES**

1. Damarla RB, Rao KN. Factors affecting firmness loss in apples during postharvest handling and cold/controlled atmosphere storage in India: A. Journal of Applied Horticulture. 2022;24(1):98-104.Rao KN, Devarakonda S, Babu DR. Mathematical modelling of pre-cooling kinetic rates during artificial ripening of banana fruits under refrigerated conditions. Test Eng. Mgt. 2020 Mar; 83:6872-9.
2. Rao KN, Devarakonda S, Babu DR. Mathematical modeling of cooling rates of mango fruits during unsteady state cooling in an artificial ripening chamber. Test Engineering and Management. 2020 Mar;83:6872-9.
3. Babu DR, Rao KN, Kumar MS, Kumar BS. Handling of apples during sorting-grading operation and measuring the mechanical properties firmness after controlled atmosphere storage. Int. J. Mech. Prod. Eng. Res. Dev. 2018 Dec;8:617-34.
4. Ramesh Babu D, Narasimha Rao KV. Mechanical compression properties of apple fruit: errors during penetrometer measurements. InData Engineering and Communication Technology: Proceedings of ICDECT 2020 2021 May 24 (pp. 493-502). Singapore: Springer Singapore.
5. BABU DR. Mathematical modeling of moisture loss, oil uptake and colour kinetics during deep fat frying of onion slices.
6. Raghava K, Babu DB, Rao KN. Mathematical modeling of temperature profiles during un-steady cooling of fruits stored in a cold store unit. International Journal of Advanced Science and Technology. 2020;9(24):5894-900.

7. Babu DR, Rao KN, Kolati S. The design of refrigeration, thermal insulation and an equipment for healthy ripening of mango and banana without using harmful chemicals. International Journal of Mechanical and Production Engineering Research and Development. 2019;9(1):423-34.
8. Babu DR, Rao KN, Kumar MS, Kumar BS. Handling of apples during sorting-grading operation and measuring the mechanical properties firmness after controlled atmosphere storage. Int. J. Mech. Prod. Eng. Res. Dev. 2018 Dec;8:617-34.
9. Babu DR, Gupta DK, Chauhan SK. Rheological characteristics of muskmelon (cantaloupe) pulp.
10. Kolati SB, Babu DR, Prasad PI, Rao KN. Low oxygen and high carbon dioxide environment in controlled atmosphere cold storage: Recommendations for safe working conditions. Plant Cell Biotechnology and Molecular Biology. 2020;21:9-14.
11. Deshmukh R, Babu DR, Rao KN. Pressure testing results (as a decision tool for deciding low oxygen or ultra-low oxygen or high oxygen storage) of semi-hermetically sealed controlled atmosphere storage insulated chambers. IJMPERD. 2020;10(1):531-40.
12. Kassebi S, Farkas C, Székely L, Géczy A, Korzenszky P. Late shelf life saturation of golden delicious apple parameters: TSS, weight, and colorimetry. Applied Sciences. 2022 Dec 23;13(1):159.
13. Ahmad F, Zaidi S, Arshad M. Postharvest quality assessment of apple during storage at ambient temperature. Heliyon. 2021 Aug 1;7(8).
14. Ding X, Zheng Y, Jia R, Li X, Wang B, Zhao Z. Comparison of fruit texture and storage quality of four apple varieties. Foods. 2024 May 17;13(10):1563.
15. Molina-Corral FJ, Espino-Diaz M, Jacobo JL, Mattinson SD, Fellman JK, Sepulveda DR, Gonzalez-Aguilar GA, Salas-Salazar NA, Olivas GI. Quality attributes during maturation of 'Golden Delicious' and 'Red Delicious' apples grown in two geographical regions with different environmental conditions. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 2021 Mar 24;49(1):12241-.
16. Malik MR, Ahmed S, Hammad M, Sharif M, Hassan RM, Ilyas M, Rehman A, Khan KU, Ahmed I, Ullah F. Impacts of Aloe Vera Gel Coating on Postharvest Quality and Storage Period of Apple (Malus domestica). Pak-Euro Journal of Medical and Life Sciences. 2024 Dec 22;7(Special 2):S317-30.
17. Lu L, Zuo W, Wang C, Li C, Feng T, Li X, Wang C, Yao Y, Zhang Z, Chen X. Analysis of the postharvest storage characteristics of the new red-fleshed apple cultivar 'meihong'. Food Chemistry. 2021 Aug 30;354:129470.
18. Shi M. PHYSIOCHEMICAL QUALITY, INSTRUMENTAL AND SENSORY EVALUATION OF APPLES TREATED BY POST-HARVEST TREATMENT TECHNOLOGIES: DYNAMIC CONTROLLED ATMOSPHERE (DCA), CONTROLLED ATMOSPHERE (CA), AND 1-METHYLCYCLOPROPENE (1MCP). 2021.
19. Rojas-Candelas LE, Chanona-Pérez JJ, Méndez JM, Perea-Flores MJ, Cervantes-Sodi F, Hernández-Hernández HM, Marin-Bustamante MQ. Physicochemical, structural and nanomechanical study elucidating the differences in firmness among four apple cultivars. Postharvest Biology and Technology. 2021 Jan 1;171:111342.
20. Gao Q, Tian YL, Zhang JH, Zhang P, Zhang M, Bi JF, Li JK, Xue YL. Discriminant analysis of 'Fuji'and 'Hanfu'apples under 1-methylcyclopropene (1-MCP) and cold storage conditions based on their postharvest quality and aroma properties. Journal of Food Measurement and Characterization. 2024 Nov;18(11):9492-507.
21. Khera K, Büchele F, Wood RM, Thewes FR, Wagner R, Hagemann MH, Neuwald DA. Impact of different storage conditions with combined use of ethylene blocker on 'Shalimar'apple variety. Scientific Reports. 2024 Apr 11;14(1):8485.
22. Kassebi S, Korzenszky P. INFLUENCE OF AMBIENT STORAGE ON WEIGHT, COLOR, AND TSS IN GOLDEN DELICIOUS APPLES: A CORRELATIONAL STUDY.
23. Ding X, Zheng Y, Jia R, Li X, Wang B, Zhao Z. Comparison of fruit texture and storage quality of four apple varieties. Foods. 2024 May 17;13(10):1563.
24. Ahmad F, Zaidi S, Arshad M. Postharvest quality assessment of apple during storage at ambient temperature. Heliyon. 2021 Aug 1;7(8).
25. Mureşan AE, Sestras AF, Militaru M, Păucean A, Tanislav AE, Puşcaş A, Mateescu M, Mureşan V, Marc RA, Sestras RE. Chemometric comparison and classification of 22 apple genotypes based on texture analysis and physico-chemical quality attributes. Horticulturae. 2022 Jan 10;8(1):64.
26. Doe JW, Crouch EM, Thirupathi Karuppana P. Harvest maturity, storage conditions and tree age influencing internal browning and fruit quality of Rosy Glow apple (Malus domestica Borkh).
27. Zhang M, Yin Y, Li Y, Jiang Y, Hu X, Yi J. Chemometric classification of apple cultivars based on physicochemical properties: Raw material selection for processing applications. Foods. 2023 Aug 17;12(16):3095.
28. Bound SA. Determination of target crop loads for maximising fruit quality and return bloom in several apple cultivars. Applied Biosciences. 2023 Nov 1;2(4):586-606.
29. Sidhu RS, Hunt I, Bound SA, Swarts ND. Crop load, fruit quality and mineral nutrition as predictors of fruit softening and internal flesh browning in modern firm fleshed apple cultivars. Scientia Horticulturae. 2024 Apr 15; 330:113035.
30. Mohammed K, Saghrouchni H, El Abdali Y, Amine A, Haoudi N, El Fadili M, Amar A, Hamijo T, Var I, Ullah R, Rachid ZA. Phytochemical and physicochemical studies of different apple varieties grown in Morocco. Open Chemistry. 2024 Mar 1;22(1):20230205.
31. Mota M, Martins MJ, Policarpo G, Sprey L, Pastaneira M, Almeida P, Maurício A, Rosa C, Faria J, Martins MB, de Sousa ML. Nutrient content with different fertilizer management and influence on yield and fruit quality in apple cv. Gala. Horticulturae. 2022 Aug 8;8(8):713.
32. Najar ZH, Kashtwari M, Zargar SA, Wani AA. Assessment of Morphological Diversity of Apple (Malus× domestica Borkh.) Germplasm in North Kashmir, India. Vegetos. 2023 Jun;36(2):651-60.

33. Abdel-Sattar M, Kotb HR. Nutritional status and productivity of Anna apple trees in the year following autumn irrigation determent. Agricultural Water Management. 2021 Jun 30;252:106882.
34. Singh Sidhu R, Bound SA, Swarts ND. Influence of harvest maturity on fruit quality and storage potential of Scilate apples. InXXXI International Horticultural Congress (IHC2022): International Symposium on Integrative Approaches to Product Quality in 1353 2022 Aug 14 (pp. 263-272).
35. Kumar A, Sharma DP, Kumar P, Sharma G, Suprun II. Comprehensive insights on Apple (Malus× domestica Borkh.) bud sport mutations and epigenetic regulations. Scientia Horticulturae. 2022 Apr 30;297:110979.
36. Sharma RR, Datta SC, Varghese E. Kaolin-based particle film sprays reduce the incidence of pests, diseases and storage disorders and improve postharvest quality of 'Delicious' apples. Crop protection. 2020 Jan 1;127:104950.
37. Ranjbar S, Ramezanian A, Rahemi M. Nano-calcium and its potential to improve 'Red Delicious' apple fruit characteristics. Horticulture, Environment, and Biotechnology. 2020 Feb;61(1):23-30.
38. Guerra M, Sanz MÁ, Rodríguez-González Á, Casquero PA. Summer pruning, an eco-friendly approach to controlling bitter pit and preserving sensory quality in highly vigorous apple cv.'Reinette du Canada'. Agriculture. 2021 Nov 1;11(11):1081.
39. Sharma RR, Pal RK, Singh D, Samuel DV, Sethi S, Kumar A. Evaluation of heat shrinkable films for shelf life, and quality of individually wrapped Royal Delicious apples under ambient conditions. Journal of food science and technology. 2013 Jun;50(3):590-4.
40. Chauhan SK, Babu DR. Use of botanicals: A new prospective for enhancing fruit quality over chemicals in an era of global climate change. Asian Journal of Environmental Science. 2011 Jun;6(1):17-28.
41. Sun C, Zhang W, Qu H, Yan L, Li L, Zhao Y, Yang H, Zhang H, Yao G, Hu K. Comparative physiological and transcriptomic analysis reveal MdWRKY75 associated with sucrose accumulation in postharvest 'Honeycrisp'apples with bitter pit. BMC Plant Biology. 2022 Feb 17;22(1):71.
42. Ornelas-Paz JD, Quintana-Gallegos BM, Escalante-Minakata P, Reyes-Hernández J, Pérez-Martínez JD, Rios-Velasco C, Ruiz-Cruz S. Relationship between the firmness of Golden Delicious apples and the physicochemical characteristics of the fruits and their pectin during development and ripening. Journal of food science and technology. 2018 Jan;55(1):33-41.