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Factors affecting firmness loss in apples during postharvest handling and cold/controlled atmosphere storage in India: A review

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Abstract

Apples attract humans with their dominant appeal and eating quality. The most dominant properties are color and texture. This review paper discusses the scientifically published results of apple texture through the understanding of internal properties like structural, physiological, physical, mechanical, water and cell wall contributions and post-harvest handling and storage methods. A critical appraisal is made of factors responsible for inner texture and sustenance during post-harvest and storage periods. The status of research data available is discussed from a firmness point of view of Indian apple varieties vis-à-vis those grown in other countries. Most of the research work on Indian apples reported physico-chemical parameters like weight, diameter, firmness, bio-chemical and nutrient components. Data for the long term in CAS (6 to 10 months) was not found in the latest literature. The research data on factors responsible for texture loss is also very limited for Indian-origin apples. There are still large gaps in research in finding firmness loss. Hence, suggestions are made on the scope for future research on apples grown in India for the benefit of farmers, traders, and ultimately the consumers.

Key words: Apple (*Malus Domestica Borkh*), firmness, quality loss, textural properties, postharvest factors.

Introduction

India produced 2.33 Million Metric Tons (MMT) of apples during year 2017-18. The difficult Himalayan terrain, poor road infrastructure and large distances to reach stores/users make apple business vulnerable for financial fluctuations. Causes of undesirable ripening are: maturity level of fruits, delay time after plucking, temperature of fruit & ambience, kind of packaging, handling practices, quickness in reaching storage or pre-cooling centers, pre-cooling time, pre-harvest and postharvest factors. Firmness is an important attribute for apple consumer. Delayed softening is essential to realize better price while selling (Johnston *et al.*, 2002). Less mealiness is associated with firmer apples. Wijewardane and Guleria (2013) reported quality parameters of Indian apple varieties with respect to pre-cooling and packaging.

Apple softening is the major problem to the growers in India. Crispy apples are not available in the market during off-seasons. Few commercial CAS facilities are created in India, to the tune of 150 MMT capacity (NCCD, 2015). Behavior of apples, locally grown in a particular country, may vary depending on variety, climatic conditions, orchard practices, pre- and post-harvest management practices compared to other country-of-origin apples. CA recommendations on oxygen and CO_2 levels for the apples grown in one area may cause injury to the same variety grown in another area (WFLO Commodity Storage Manual, 2010). Postharvest technologies for developing countries and challenges associated in research, outreach and advocacy were recommended by Kitinoza *et al.* (2011). Some of the important research reports focusing on the apple fruit texture and its retention are discussed in this review paper.

Firmness of cultivars grown in India: Apples at right maturity are firm in texture at the time of harvesting. Firmness range (20 to 24 Lbs) is reported for Royal, Red, Rich-a-red, and Golden apples, of which golden delicious apples have thin peel and retain less firmness during cold /CA storage (Ramesh Babu *et al.*, 2018). Kumar *et al.* (2018) reported the nutritional characterization of 22 apple cultivars grown in Himachal Pradesh (HP). Out of five non-red varieties of apples, the highest firmness was found in winter banana (14.00 N) and the lowest in Stark Spur Golden (10.53 N). Out of 17 red cultivars, the highest firmness was found in Spartan and Red Delicious. The lowest firmness was found in Starkrimson, Silver Spur and Vance Delicious varieties. Pre-cooling, natural extract coatings, and packaging retain better firmness after 45 days of storage at 18-25 ^oC (Wijewardane and Guleria, 2013). Sharma *et al.* (2013) reported the beneficial effect of heat shrinkable films on apple quality. Firmness changes, along with decay loss, juice recovery, and PLW were measured for seven weeks at 22-28 ^oC storage. Hydro cooling, paraffin waxing, and $CaCl_2$ treatment for Red Delicious apples of J&K were found beneficial. Treatment with hydro cooling + 3 % $CaCl_2$ + 6 % Paraffin Wax was promising and beneficial, followed by treatment with hydro cooling + 3 % $CaCl_2$ to retain the more physical quality attributes under both storage conditions (Wijewardane and Guleria, 2013). Jha *et al.* (2012) studied Golden Delicious, Red Delicious, Ambri and two unknown varieties of Indian origin, and reported the physico-chemical parameters. The overall quality index was correlated with the sensory and physico-chemical parameters.

Unit of measurement of firmness as reported in literature: Most of the researchers expressed the firmness units as lb in^{-2}. The instrument most commonly used is a penetrometer (Ganai *et al.*, 2018). The firmness values reported by Kumar *et al.* (2018) appear much lower than the values reported by Wijewardane and Guleria (2013) due to the reason that in the first case, the tests were conducted on a texture analyzer. However, care has to be taken for the proper record of firmness, like holding the instrument in proper position, penetration speed, depth of penetration, *etc.*, (Ramesh Babu and Narasimha Rao, 2021).

Texture breakdown: Apple texture can be explained by responsible factors both at preharvest and postharvest stages. Johnston *et al.* (2002) has reviewed the factors responsible for apple fruit postharvest softening. Fruit anatomy and cell packing, cell wall, cell membranes, cell turgor, ethylene, and apoplastic pH are thoroughly discussed apart from pre and postharvest factors. The effects of calcium treatments, relative humidity, controlled atmospheres, and short-term stress treatments are detailed. A detailed review was conducted by them on several enzymes responsible for quality changes in apples. Texture loss in apples was reported in several perspectives. Correlation with sensory properties (Cliff and Bejaei, 2018), acoustic and mechanical signatures (Costa *et al.*, 2012), peel contribution on texture measurement (Costa, 2016), cell turgor correlated to micro-mechanical properties (Oey *et al.*, 2007). Textural properties of different varieties and country of origin are given in Table 1. Firmness measurement without penetration or compression tests is of great interest, which saves time for quality test, and apples need not be disposed off due to destructive test. Various researchers successfully demonstrated use of several non-destructive methods for predicting firmness of apples, which are given in Table 2.

Factors affecting apple texture loss

Pre cooling and temperature: Temperature plays an important role in controlling respiration rate, thereby associated mechanisms of pectin degradation, transpiration, and firmness loss. Cooling of fruits immediately after harvest is a critical requirement for controlling temperature-regulated bio-chemical changes. Apples need to undergo pre-cooling before being preserved in cool/ controlled atmosphere storage. Major apple-producing states in India do not have sufficient pre-cooling facilities. The difficult terrain and road infrastructure make hurdles for the transportation of apples in temperature-controlled vehicles. Typical temperatures for apple cooling are in the range of 0 to 5 ^{o}C.

Relative humidity & moisture loss: Relative humidity (RH) ranging from 90 to 95 % is desirable to avoid shrinkage and moisture loss. Low RH can cause economic losses to the produce store operators. Firmness loss and weight loss due to transpiration happen simultaneously in the storage chambers. However, specific relation of RH on firmness needs to be studied. The moisture content in fruits is in the range of 85 to 98 percent, the remaining being the solids. The moisture being the major physical constituent in the apple, contributes to cell turgor and supports the bio-chemical changes. Mitropoulos and Lambrinos, (2005) reported a significant relationship between moisture loss and firmness changes.

Freezing/chilling injury: Freezing causes irreversible damage to apple texture. Apples need to be protected from sub-zero temperatures at orchards and CS/CAS. Fruits become unmarketable due to chilling injury and spongy flesh develops due to firmness loss (Watkins and Jackie Nock, 2004). Freezing injury happens at temperatures below -1.7 ^{o}C and apples are categorized as 'moderately susceptible" compared to other fruits (WFLO, 2010). Kader (2010) clarifies that moderately susceptible fruits recover from one or two light freezes. ElMasry *et al.* (2009) modeled the freezing injury for red delicious apples (exposed to -1 ^{o}C for 24 h) using hyper-spectral imaging and neural networks. Studies need to be conducted to find the extent of fruit exposure to sub-zero temperatures and its effect on texture loss.

Internal factors: The effect of intracellular water (Lahaye *et al.*, 2018), gas distribution, and chemical composition on apple dynamic mechanical properties were found to be significant (Winisdorffer *et al.*, 2015). Effect of these parameters on mechanical properties were reported by Winisdorffer *et al.* (2015) during their study on six varieties of apples grown in France, and they found a link between cell wall constituents and mechanical properties of apple tissue. Texture correlation with cell wall changes was reported for Cox's orange pippin apple. Significant relations were found between apple firmness, extractable juice content, and cell wall changes observed under CA conditions. Gwanpua *et al.* (2016) reported a slow-softening apple variety, "Kanzi" which loses crispness very slowly. Kanzi apples were found to be distinctly different compared to any other variety in respect of being crispy during ripening. The low ethylene production and limited pectin de-polymerization and solubilization were found to be associated with slow softening behavior. Tissue failure was mainly due to cell breakage. In contrast, they compared the behavior with that of golden delicious, in which a high level of pectin de-polymerization was accompanied by solubilization and softening.

Ethylene and pectin composition: Ethylene production due to increased respiration is a major cause of quick ripening and firmness loss. The role of pectin was significantly correlated with mealiness from a sensory point of view and its effect on firmness can only be confirmed with other factors like size, the shape of the cells, cell thickness of tissue of fruit, and also water osmotic pressure & intercellular space to explain macroscopic scale fruit texture (Billy *et al.*, 2008). They made correlations of biochemical markers concerning to sensory and instrumental measurements of Fuji and Golden Delicious apples. Gwanpua *et al.* (2014) reported the role of enzymes and pectin modifications in the softening of Jonagold apples and concluded that ethylene production is positively correlated with softening rate.

Sorting and grading: Sorting and grading at the orchard level is very crucial in respect of proper packing, uniformity in size, shape, color, and other properties. Any uneven size of packing and grading cause losses during transportation. Stacking, compression, and inter-fruit contact damage can severely affect the storage firmness retention. Apples of good quality and long storage potential should only be stored in CAS (WFLO, 2010). This indicates the importance of sorting, grading, and quality segregation. Ramesh Babu *et al.* (2018) reported the effect of sorting-grading protocols and handling practices on apple quality during CAS. Apples get bruised due to vibrations, improper handling during harvesting and grading, impact loads (Barikloo

Table 1. Various textural properties, instruments and critical findings related to apple firmness

Variety	Origin	Storage temperature (^0C)	Storage period	Instrument used	Textural properties measured	Critical findings	Reference
Golden, Delicious & Rome beauty	Southern Pennsylvania, Beltsville, US	0	--	Instron Universal Testing machine	Deformation, Failure stress and Young's modulus	Measured mechanical properties from geometrical directions of apple. Anisotropic properties were more pronounced at middle section than top and bottom portion of apples.	Abbott and Lu (1996)
Red spur, Delbarstival	Iran	4	--	Universal testing machine	Physical & Mechanical properties	Stress and Strain properties reported	Kheiralipour *et al.* (2008)
Cox's orange pippin, Sciros, Scifresh and Sciearly	New Zealand	3 for Cox's orange pippin, 0 for others in cold store	240 days	Puncture test using Instron fitted with Effigi Penetrometer probe, Single Edged notched bend test(SENB)	Fracture force, tensile and SENB fracture toughness, fracture energy and Young's modulus	Relation between firmness and fracture parameters established. Scifresh found to be extremely firm compared to other three.	Harker *et al.* (2006)
Qinguan, Ben Davis	China	2-4	4 months cold store	Texture analyzer-TMS-Pilot	Textural, Ultra-structural properties	Ultra structural cells of course cultivars degraded (cell wall tissues were under observation)	Li *et al.* (2019)
Sciearly, Cox's orange pippin, Royal gala, Honey crisp, Scifresh, Sciros, , Cripps pink	New Zealand	3	Tested for few days after harvest	Materials testing machine-Instron	Firmness	PCA and discriminant analysis along with sensory juiciness correlated the postharvest textural assessment	Brookfield *et al.* (2011)
Pink Lady	California, US	0.5	2,4,6 months in air and CA	Fruit texture analyzer-Guss	Firmness	Firmness loss up to 6 months with different CA conditions reported along with comparison of air storage	Castro *et al.* (2007)
Elstar, Jonagold and Gloster	Poland	3	Normal atmosphere, Standard CA & low CA for 120,135,165 days	MT probe -Instron	Firmness	Firmness changes reported with respect to different CA conditions and relation between firmness and texture acceptability	Konopacka and Plocharski (2004)
Jonagold, Braeburn and Kanzi	Belgium	1	4 or 6 months in CA	LRX Universal Testing Machine	Firmness	Mathematical modeling of firmness loss and slow ripening of Kanzi reported	Gwanpua *et al.* (2013)

Table 2. Non destructive methods used for predicting firmness of apples

Non destructive principle	Varieties studied	Origin of apple	Observations	Reference
Laser-induced plasma shock wave	Sun Fuji	Japan	Flesh firmness measured with oS_2 mode of natural frequencies	Hosoya *et al.* (2017)
Ultrasonic parameters	Golden delicious	Iran	Elastic modulus modeled using force-deformation	Vasighi-shojae *et al.* (2018)
Capacitance measurement and acoustic properties	Red delicious of Kinnaur region	India	Voltage across inductor measured and correlated with shelf life	Bhosale and Sundaram (2014)
Electronic nose system	Gala	Virginia	Principle component analysis of measured aroma components using head space gas sensors	Pathange *et al.* (2006)
Acoustic impulse resonance frequency & VIS/NIR spectrometer	Idared and Golden delicious	Germany	Partial least squares calibration models on acoustic data and VIS spectra were built to correlate flesh firmness	Zude *et al.* (2006)
Acoustic emission	Topaz, Szampion, Gloster, Idared and Ligol	Poland	Total acoustic emission and firmness through puncture test are correlated	Cybulska *et al.* (2012)
Optical absorption and scattering	Golden delicious and Granny smith	Michigan	Mechanical and structural properties correlated with optical absorption and scattering properties through hyper-spectral images	Cen *et al.* (2013)

and Ahmadi, 2013), and mechanical damages. Measurement of bruising using several methods is well documented (Baranowski *et al.*, 2009; Ahmadi *et al.*, 2016; Zhang *et al.*, 2017).

Packaging: A good packaging system protects apples from bruising or damage during transportation and storage. Any bruise can cause firmness loss and decay. CFB Cartons with separator pulp trays or wooden boxes are used in India. Proper ventilation is required in CFB cartons for effective cooling (Pathare *et al.*, 2012). Proper ventilation, without compromising the strength of the packing, offers several advantages, including the prevention of localized ethylene accumulation, higher CO_2 levels, and spoilage (Subedi and Giri, 2017).reported that CFB cartons without ventilation significantly affected the firmness and decay. In the international market, CFB Cartons with polythene liners, and bubble cushion sheets are used. Plastic foam trays and individual bubble wrap packages are popular due to the beneficial effect of shock and vibration absorption. The effect of natural cushioning materials like botanicals is well documented by (Chauhan and Babu, 2011). Apples during storage are commercially preserved in three methods. The first one is in CFB Cartons directly, the second one in wooden boxes, and the third and most recent practice is placing apples in plastic jumbo crates. CFB carton packed apples are directly stored in cold stores at 0 to 5 °C which have more possibilities for localized gas accumulation within the carton and thereby less shelf life. The wooden box packing has also got the same problems during storage. However, apples sorted, graded, and stored in perforated plastic bins have got better shelf life due to improved flow distribution of cooler air inside the apple bin (Scaar *et al.*, 2016) and better air circulation (Vigneault *et al.*, 2005). Plastic bins are self-stackable and avoid stacking a load onto the apples, otherwise happens in the case of CFB cartons. The stability and strength of fruit bins are important while designing the bin. Alam *et al.* (2014) studied the structural design using finite element modeling to ensure stability and strength to meet several types of loading onto the bin.

Surface coatings and treatments: Surface coatings and treatments are successful in controlling respiration and transpiration losses apart from microbial safety. Beneficial effect in terms of firmness and other quality parameters were found during cool storage with calcium chloride (Sharma *et al.*, 2013; Banoo *et al.*, 2018; Ranjbar *et al.*, 2018), and paraffin wax with hydro cooling combination (Ganai *et al.*, 2018), neem based formulations as pre-harvest treatment (Chauhan *et al.*, 2012), oil and extracts (Shweta *et al.*, 2014). The latest research work on calcium sprays was reported by Ranjbar *et al.* (2018), who recommended nano-calcium for retaining firmness. Chauhan and Babu (2011) reported that 1.5 % Nimbecidine treatment retained the firmness along with reduced moisture loss (PLW). Apples coated with 20 % marigold extracts and oil and shrink wrap films were found beneficial in extending shelf life at room temperature (Wijewardane and Guleria, 2013). Beneficial effects of *aloe vera* edible coatings on apples are reported by Shweta *et al.* (2014). Use of different starches 2 % (rice, potato, corn) along with oil improved the overall quality retention up to 150 days at 2°C (Wijewardane and Guleria, 2009).

Transportation from harvest to market/storage points: Shifting apples from orchards to CA/CAS must happen without any time delay. Irreversible damage happens to the apple during the immediate postharvest time. Respiration causes the production and accumulation of ethylene and leads to ripening and firmness loss. The effect of time gap on the extent of damage to firmness loss temporarily or permanently needs to be studied, as no such reports are available in the literature. The Delay in cooling after harvest was described in commercial terms by the National Horticulture Board (NHB, 2010). That delay by one day at 21 °C after harvest takes off seven to ten days of shelf life at 0 °C in the store. This has not been reported with scientific research outcomes, however, and indicates the severity of the situation and the need for research required in this. The influence of delayed cooling affects negatively on the quality of apples during storage (Delong *et al.*, 2004).

Mechanical damages during handling and transportation: Apples, either packed in wooden boxes or CFB cartons or plastic crates, are prone to injuries during their handling and transportation. The bruise-causing aspects are found to be impact loads (Van Zeebroeck *et al.*, 2007; Stropek and Golacki, 2016;

Stopa *et al.*, 2018) and, impact and compression forces causing tissue disruptions (Bender *et al.*, 2018). Van Zeebroeck *et al.* (2007) thoroughly reviewed the causes of impact damage and reported on factors like individual fruit to fruit impact, fruit container drop impact, transport vibration of fruit bin, transport vibration response to road surface, cushioning and damping property of packing material, box dynamic response, container to fruit friction, dynamic interaction of packing material to fruit, susceptibility of apple to damage as a function of temperature, cultivar, size and maturity. Bruising must be avoided during sorting, grading, packing, loading and unloading, transportation and storage. Apple bruise measurements must be done to eliminate or segregate good fruits from bruised fruits for retaining better firmness during storage. Most prominent analyses are: Effect of pre-harvest factors on bruising (Hussein *et al.*, 2018), measurement of bruises based on optical properties (Zhang *et al.*, 2017) and bruise responses due to apple-to-apple impact (Fu *et al.*, 2016), predicting apple bruise volume using Artificial Neural Network (Zarifneshat *et al.*, 2012). Opara and Pathare (2014) have reported bruising damage measurement of horticulture produce through a review paper.

Nutritional characterization and genotypes: Kumar *et al.* (2018) conducted an extensive study with 22 types of apple cultivars in Himachal Pradesh. Nutritional characteristics like sugars, total carotenoids, antioxidant activity, organic acids, phenolic compounds, ascorbic acids, and minerals are reported along with firmness, color, dimensions, and other physical parameters. Genes responsible for apple fruit firmness degradation are reported by Nybom *et al.* (2010) in detail.

Pre harvest factors: Apple quality has been found to be significantly related to pre-harvest factors. Cultivars, external quality, internal quality, environment, and agronomic factors, and maturity indices affect the quality of apple. Musacchi and Serra (2018) in their review article, presented important factors like rootstock mechanism, size, shape, color, russeting, texture, and firmness; starch, soluble solids, acidity, ethylene, fruit chlorophyll content, dry matter; environmental conditions, temperature, light, sunburn; agronomic factors, pruning, crop load, thinning, pollination, nutrition, maturity indices, orchard management, calendar date and day after full bloom, fruit retention strength and abscission. High firmness at harvest will result in better firmness retention during storage (Goncalves *et al.*, 2017). As these factors are well documented, these factors are not much discussed in this study.

Controlled atmosphere storage (CAS): CAS extends the life of seasonal perishable produce when refrigeration alone is not sufficient. Oxygen, carbon dioxide and temperature levels affect the storage behavior and depend on cultivars, growing conditions, maturity and postharvest treatments. Limited CAS facilities are installed in Uttarakhand, HP, and Haryana. The commercial success of CAS depends on the implementation of appropriate technologies. It is necessary to select the most suitable postharvest handling technologies based on the commodity-specific studies. The latest technologies in CAS include Dynamic Controlled Atmosphere (DCA) where sensors connected to the produce will direct the dynamic systems controlling gas composition and temperature (Mditshwa *et al.*, 2018).

Published work on apples grown in India is limited to mostly pre-cooling, coatings, and packaging effects in comparison to extensive research reports on these aspects for apples grown in the USA, Italy, Poland, Canada, China, New Zealand, Iran, *etc.* It is well accepted by scientists that storage behavior is highly dependent on factors like cultivar, genetic factors, climate, orchard management, pre and postharvest methods, and postharvest storage broadly. So, there is a need to conduct research on genetic factors, enzyme's role, and different CA compositions for different apples grown in India, so that apples with good firmness can be made available throughout the year. This will reduce the loss of valuable payout to imported apples. Even though postharvest scientists / workers conducted a lot of research on apple storage, further research needs to be conducted on the effect of transportation time from orchard to storage; sorting of bruised or mechanically damaged fruits; grading as per size and color before storage; different packaging bins or boxes for bulk or retail storage; storing apples in bulk storage based on specific respiration behavior, size, variety, and compatibility among varieties stored in CAS/CS and tolerance to mechanical bruising for retaining firmness.

The following areas of research are identified for Indian-grown apples: (i) Storage behavior of different varieties of apples (ii) Effect of fruit size, and maturity on apple texture during CA storage. (iii) Standardization of CA gas conditions for different apple varieties (iv) Modeling rate of texture breakdown during long-term CA storage.

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