Physiological changes in apple fruit in response to physical damage received during post-harvest handling practices

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Abstract

The apple fruit quality features decrease during improper harvesting and post-harvest handling practices. The apple fruits primarily undergo mechanical damages, like bruised impact, and compression forces. Besides increasing the production level, care and optimization during harvesting and post-harvest operations are necessary for preserving the quality and maintaining the storage life. Therefore, this work aims to observe the physiological changes in apple fruit caused by physical damage and compression during post-harvest operations. The experiment comprised five treatments of a combination of fruits dropped before storage and compressed during storage. In apple fruits, the bruising led to elevated ethylene production levels (1.65-19.81 nL ethylene g^{-1} h^{-1}), which induced respiration rates and weight loss. Enhanced ethylene was observed particularly in dropped and laterally compressed fruits. The firmness levels, however gradually declined in all treatments. The sugar contents of the stored apples were slightly enhanced, while the acidity level gradually reduced. On the other hand, the flesh color range (L^*, a^*, b^*) values had variation, but it was not significant. Nevertheless, the bruising area in the surface and flesh parts due to free dropping was expanded and affected the quality. On the whole, free dropping and compression on the lateral sides of the fruit triggered increased bruised area and physiological changes. Proper harvesting and post-harvest handling practices are the primary concerns to take into consideration in Afghanistan. Establishing post-harvest facilities, such as processing centers, local and typical storage facilities, and market infrastructures is recommended to be necessary for decreasing losses and maintaining quality and shelf life.

Keywords: dropping damage, compressing, ethylene, respiration, distractive and non-distractive treatments.

چکیده:

ویژگی‌های کیفیت میوه سیب در زمان برداشت نامناسب و عملیات پس از برداشت کاهش می‌یابد. معمولاً محصول سیب در معرض آسیب‌های مکانیکی مانند ضربه خوردگی, کبودی و فشرده سازی قرار میگیرد . علاوه بر افزایش سطح تولید، مراقبت و بهینه‌سازی در زمان برداشت و عملیات پس از برداشت برای حفظ کیفیت و افزایش عمر ذخیره سازی محصولات ضروری پنداشته میشود. بنابراین، هدف این رساله یا تحقیق عبارت از بررسی تغییرات فیزیولوژیکی محصول سیب ناشی از آسیب‌های میکانیکی (ضربه خوردگی) و فشرده‌سازی در طول عملیات پس از برداشت میباشد. آزمایش شامل پنج تیمار یا روش، ترکیبی از محصولاتیکه قبل از ذخیره‌سازی از ارتفاع معین جهت ایجاد ضربه خوردگی، رها گردیده و و تیمارهایکه در جریان ذخیره سازی در معرض فشرده سازی قرار گرفته، تشکیل شده است. در تیمار های که تحت فشار قرار داشتند، ضرب زدگی منجر به افزایش سطوح تولید اتیلن 1.65-19.81 nL ethylene g-1 h-1) گردیده که این کار باعث افزایش میزان تنفس و کاهش وزن محصول گردیده. از طرف دیگر، سطح افراز اتیلن به خصوص در نمونه های که از ارتقاع معین سقوط داده شده زخمی گردیده و در تیمار هایکه در جریان ذخیره سازی تحت فشار معین در سطح جانبی قرار گرفته بودند افزایش یافته است. با این حال، سطوح استحکام نمونه ها به تدریج در تمام تیمار ها کاهش یافته، محتوای قند نمونه ها در جریان ذخیر سازی، اندکی افزایش را نشان میدهد، در حالی که سطح اسید یا ترشی نمونه ها در جریان ذخیره به تدریج کاهش داشته است. از طرف دیگر، محدوده رنگ قسمت گوشتی نمونه ها، مقادیر (L^*, a^*, b^*) دارای تغییرات بود، اما این تغیرات معنی‌دار نبوده است. با این حال، سطح ضربه خوردگی یا کبودی نمونه ها در بخش سطحی و گوشت میوه به دلیل سقوط از ارتفاع معین و ایجاد زخم، گسترش نموده که بر کیفیت نمونه ها تأثیر مشخص داشته است. به طور کلی، سقوط آزاد و فشرده‌سازی در جهت جانبی نمونه ها گسترش یافته که متعاقبا این کار باعث تغییرات فیزیولوژیکی معنی دار در نمونه ها گردیده است. به منظور کاهش ضایعات، حفظ کیفیت و افزایش عمر ذخیره سازی محصولات، تطبیق عملیات خوب در زمان برداشت و عملیات پس از برداشت بسیار مهم و ضروری بوده که لزوما باید در نظر گرفته و عملی گردند. جهت حفظ کیفیت و طولانی ساختن عمر ذخیروی محصول، ایجاد تاسیسات و امکانات پس از برداشت، مانند مراکز پروسس، ذخیره خانه های محلی و سرد خانه های معمول، و زیرساخت‌های بازار ضروری میباشد.

1-Introduction

Agriculture is the backbone of Afghanistan's economy. Around 60 % of its population are employed and earn their income from the agricultural and livestock sectors. It is obvious that Afghanistan has a long tradition and history in horticulture for its quality products, however, recent instability such as conflict, and extended periods of drought have destroyed lots of its infrastructure and potential. Throughout civil wars and conflicts, a large number of horticulture infrastructures were demolished, and research centers, water resources, and fruit orchards were destroyed.

Apples are temperate climate fruit. They are native to many parts of Europe and Asia-temperate climates. The origin of apples is Central Asia, and Afghanistan has many areas with native apples. Wild apple varieties, such as Malus pumila, Malus silvestris, and Malus orientalis are the most prevalent. In 1997, an amazing 44.7 million MT of apples were produced for human consumption. In 2006, production was 44.1 million MT. The leading apple-growing country is China, producing about 41% of the world's apples, followed by the United States [1]. Afghan apple is amongst the sweetest, firmer, large with a conical shape, and has desirable flavor and colors. Mostly apples are grown in the central provinces of the country. However, apples have been produced in widespread areas throughout the country. During 2008-09, the total production of apples in Afghanistan was estimated at 77,000 MT harvested from 7,000 ha of land. Thus the average yield is 11 MT per hectare or 2.23 MT per Jireb, (a unit of land which is commonly understood in the country) [2].

The apples are well-suited climatically and have relatively large-scale cultivation areas and higher income generation. Demands are increasing for its production due to its nutrition, longer shelf life, and reasonable price. It has played a significant role in the past and still is an important high-yield crop for a stable and prospering community.

Local apple products are hard enough and have a relatively long shelf life if stored properly and could maintain their quality, nutrition values, and flavor for quite an extended period in optimal storage conditions. Commercial apple production is concentrated in the colder and most central provinces of Afghanistan such as Maidan Wardak, Kabul, Logar, Ghazni, Paktia, and Kandahar Provinces. Most exports take place from these Provinces. According to the Ministry of Agriculture, Irrigation, and Livestock (MAIL), both apple production volume and production area have greatly increased through the past years and reached its maximum level in 2022 to ۳۱۸٤۰۲ MT harvested from ۳۰۱٦۳-hectare of areas [3].

However, on the other hand, along with the increase in production, several problematic issues arise from harvesting and post-harvest operations. A significant amount of Apple products is lost before reaching the final consumer because of physical damage impacts such as mechanical injuries during rough handling, compression, vibration forces, and other undesirable forces causing loss of quality and quantity.

The main problems reflected to be traditional harvesting manner with less care, lack of skilled laborers, limited knowledge, and skills of the farmers concerning the post-harvest operations, lack of necessary harvesting equipment, and unavailability of suitable grading and/or sorting and packing facilities. Low-packing materials, overfilling, and stacking the packages also caused bruising. The unsuitable transportation system uses local transport trucks without considering cool chain, over-loading, and rough loading or unloading practices resulting in bruised, stress, and compression, which significantly decrease quality and contribute to losses. During these harsh and severe handling, the apple products mainly get bruised by physical damage, compression, and vibration forces which trigger considerable loss of quality and quantity, softening, decay, spoilage, and other undesirable physiological disorders. These losses severely affected producers and other key players in the market chain and caused price variation, unavailability, and a low return.

As mentioned above, in rural areas, farmers have been facing a lack of awareness and facilities to handle their products properly during harvesting and post-harvesting operations. There are not sufficient storage facilities such as storage spaces, processing centers, etc, even in those provinces where apples are produced on a large scale. Furthermore, apples are locally stored in traditional homes, rental shops, and other unsuitable places, where the temperature and relative humidity do not control, and fruits are stacked and overloaded resulting in bruised impact and other undesirable physiological changes. These facilities are mainly built for living utilization, essentially not for storing purposes. While others are digging trenches, keeping the product in the ditches and underground during the winter season to avoid chilling injuries. All of these local storage behaviors resulted in severe loss of quality and quantity, softening, decay, spoilage, and other physiological disorders.

Horticultural products, especially apples are highly susceptible to physical damage during transportation and post-harvest handling [1, 4]. The need to provide high-quality products without blemishes, cuts, bruises, physiological disorders, and pathogens is important and is emphasized by consumers [5, 6, and 7]. Various studies have been conducted which indicate that impact, compression, and vibration forces account for the majority of the mechanical damage of horticultural products [8, 9, 10, 11, 12, 13, 14, 15].

Therefore, the primary purpose of the current work is to find out physiological changes in apple fruit in response to bruised impact, compression, and other mechanical injuries received during rough harvesting and post-harvest operations. More precisely, this practical work addresses the negative impact of physical damage on physiological changes which causes significant quality and quantity loss of apples in particular, after harvest and during storage practices. This research further suggests possible solutions for decreasing the loss level and maintaining quality, safety, availability, and nutrition values through a series of proper and feasible post-harvest operations. Establishing post-harvest facilities, such as processing centers, local and typical storage facilities, smooth handling, transformation through establishing processing factories, and construction market infrastructures is recommended to be necessary for decreasing losses and maintaining quality and shelf life.

2-Literature review:

The post-harvest sector includes all points in the value chain from production in the field to the food being placed on a plate for consumption. Postharvest activities include harvesting, handling, storage, processing, packaging, transportation, and marketing [16]. In these periods, fruits are handled to be transferred properly to the final destination. Post-harvest treatment largely determines quality parameter whether a crop is used for fresh consumption or used as a processed product. The three main objective of applying postharvest technology to harvested fruit and vegetables are; (1) To maintain quality (appearance, texture, flavor, and nutritional values). (2) To protect food safety (3) and to reduce losses between harvest and consumption [17]. The most important goals of post-harvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage [18]

The post-harvest system should encompass the delivery of a crop from the time and place of harvest to the time and place of consumption, with minimum loss, maximum efficiency, and maximum return for all involved [19]. Since the fruits are alive, they tend to deteriorate soon after harvest. The rate of deterioration varies depending on the distance from farm to the market, fresh use or storage purposes, the volume of the commodity and physiological activities such as respiration rate, temperature, and humidity, etc. Nevertheless, for many fruits, this process can be rapid. For small and simple marketing channels where the product is delivered from farm to the consumers within a short period, the deterioration rate of post-harvest has little impact on quality. However, in large production scale and distance market, the losses level seems to be higher from the production site to the final destination due to the relatively long market chain, distant markets, transportation, etc. The role of post-harvest technology is to develop methods by which deterioration of the products are minimized during the period between harvest and consumption and to ensure that maximum market value for the products is achieved [20].

It has been reported that around one-third of the freshly produced crops never consumed by the final consumers caused by losses and wastage between productions and consumption worldwide. Food and Agriculture Organization of the UN predicts that about 1.3 billion tons of food is globally wasted or lost per year [21]. Losses are very huge, various authorities have been estimated that more than 30 percent of horticulture perishables are lost after harvest, and these losses could assume considerable economic significance. That is why these perishable commodities need very careful handling at every stage so that deterioration of products is restricted as much as possible during the period between harvest and consumption [22].

More attention and attempts have been assigned in production section. Around 90% of the research, investment, etc. devoted to enhancing production volume. According to Kader (2005) [23], Over the past decades, significant focus and resources have been allocated to increase food production. For example, 95% of the research investments during the past 30 years were reported to have focused on increasing productivity and only 5% bound for reducing losses. Increasing of agriculture commodity productivities are significant to be taken into consideration. However, this is not sufficient. Currently, food production level is remaining a huge challenge by limiting lands, lack of water, as well as weather variability due to climate change. In the direction of consistent fulfillment of food security, availability, and accessibility of agriculture crop are also must be increased through a reduction in post-harvest losses in the producer, market, as well as retail and consumer levels.

The primary goals of research on postharvest biology and technology of fresh produce are to reduce losses in quantity, and quality and to maintain safety between harvest and consumption sites. The strategies for attaining these goals include: (1) growing cultivars that have good flavor and nutritional quality plus long postharvest life potential when harvested at optimum maturity; (2) using an integrated crop management system that maximizes yield without sacrifice quality: and (3) using optimal postharvest handling practices to maintain quality and safety of the food products. Recent studies and literature reviews confirmed that post-harvest losses are still high at the farm, wholesale and retail levels, and that not much improvement in the overall percentage of losses can be documented from the1970s to the present, despite active horticultural education and research programs in many countries [24].

According to many studies, farmers have been losing 30-40% of the value of their fruits and vegetables before they reach the final consumer [25]. The post-harvest losses observed in various stages mainly at harvesting, grading/sorting, packing, and transportation operations. Furthermore, losses exist in the market chain such as fresh wholesale markets, and retail levels, in these places products are handled inappropriately due to mechanical injuries which receiving during various practices, eventually resulting in loss of quality and quantity such as weight loss, decay, and spoilage. Physical and quality losses mainly occur due to poor temperature management, use of poor quality packages, rough handling, and a general lack of education regarding the needs for maintaining quality and safety of perishables at the producer, wholesaler, and retailer levels [26].

Apple fruit is suffering from loss of quality due to impact damaging over harvesting and post-harvesting operations. Bruised impact occurs during harvesting, due to rough harvesting manners, unskilled laborer force, and unavailability of necessary harvesting equipment. Losses during grading or sorting and packaging also happened, possibly because of inaccessibility of packing houses, poor packing materials, improper packing manners, etc. Furthermore, losses during transportation due to vibration and compression are prevalent caused by overfilling the package, overloading the cargos in the truck along the way from the farm to the final destination. Bruised and compression due to rough and improper handling are common in developing countries including Afghanistan. Losses during transportation mostly occur caused by vibration from shaking and other stresses during handling. According to Berardinelli, et al. (2003) [27], Vibration due to transportation is influenced by the road roughness, distance, traveling speed, truck suspension, load, and a number of axles.

Consumer's demands for the better product have been increasing. On the other hand losses due to physical damage during harvesting and post-harvest operations put a negative impact on quality attributes and caused a decrease in supply level and increase prices. Apple fruits are very susceptible to mechanical damage during various post-harvest operations, rapidly losing quality and become further susceptible to pathogen attack which causing decay, rotting and spoilage.

The problem is not restricted to visual aspects, however, higher risk of bacterial and fungal contamination, leading to a lower shelf-life, also results from this damage. Other collateral effects include water loss; moisture loss of a single bruised apple may be increased by as much as 400% compared to that of an intact apple [28]. For most of the perishable fruits including apple, bruising, and stresses are the common type of post-harvest injuries which caused huge losses, and some pathogen causes fungal diseases, which mainly enter through wounds, cuts and other types of physical injuries to the fruits. If mechanical injuries could be reduced there would be much less loss of fruit in the subsequent storage lifespan. It is reported by Knee and Miller (2002) [29], apple bruising could result in product losses up to 50%, although typically loss levels are in the 10–25% range, depending on consumer awareness.

As the fruit is deteriorating and decreasing its quality after harvest, rough harvesting further increases this deterioration. During harvesting, the product must be gently hand-picked with skilled laborer and necessary harvesting equipment such as ladder, bins, baskets, etc. Maturity stage is necessary to bear in mind. Matured fruit shrink and rapidly losing moisture soon after harvest, overripe fruit exposed to softening, mealiness and has extremely short storage life. Therefore care must be taken to harvest desirable matured fruit for fresh use and storage purposes. Laborer should be well-trained and educated properly to could harvest correctly, pick the desired fruits in a proper manner with most care. Picking must be done very smoothly and carefully, and fruits should be picked with their stems, fruits without stem affected soon after harvest by a pathogen, and consumers rejecting fruit without a stem. If the fruit does not detach easily from the plant, the force of the hand can damage it.

Recently mechanical harvesting has improved, however, hand harvesting has more advantage than machine harvesting. People can precisely determine desirable product quality whereas the machine cannot. The goal of harvesting is to harvest a commodity from the field at the proper level of maturity with a minimum of damage and loss, as rapidly as possible. Today, as in the past these goals are best achieved through a hand harvesting in fruit, vegetable and flower crops [30].

3-Materials and methods

Physical damage treatments during storage

The 'Fuji' apples (*Malus* x *domestica Borkh*. cv Fuji) were hand-harvested from a high-density commercial orchard at a commercial maturity stage. A total of, 160 visually defect-free apples were randomly chosen. They were initially weighed and stored at 2°C and 85 ± 3% RH for 84 days in a cold chamber. The experiment comprised five treatments: control (CT) without any intervention and/or damage, compress vertically (CV) stressed by weight pressure, compress horizontally (CH) stressed, dropping damage plus compress vertically (DCV) stressed, and dropping damage plus compress horizontally (DCH) stressed.

For the dropping damage, the apples were released from 100 cm height to undergo a free fall to make a damaging impact before being kept in storage. For the compressing, they were pressed laterally and vertically during the storage period. The compressing weight was 1.5 fold than the average weight of each apple, which was recorded at 300 g. The samples were placed in containers or jars with a volume was 900 ml. Four containers for each treatment were prepared, and one fruit was kept in each container. Four containers (replications) were used for non-destructive measurements of each treatment, and the samples were first kept in perforated plastic fiberboard baskets, and then placed in containers or jars for measuring gaseous parameters.

Measurement of physiological and appearance characteristics

The experiment was divided into two major parts: (1) non-destructive and (2) destructive. For non-destructive measurements, ethylene production and respiration rate were evaluated by gas chromatography (Shimadzu, GC-14A) after 3 hours of sealed incubation in the container at each measurement point, and analyzed as a (ppm) amount of gas, and then calculated as (nL ethylene.g^{-1}.h^{-1}) and (nLCO_2.g^{-1}.$h^{-}1$), for ethylene and respiration, respectively. The weight loss (%) of the fruits was assessed periodically with a digital scale (METTLER PJ400).

For destructive measurement, soluble solid content (SSC) and acidity level (%) were measured by a digital refractometer (Atago, PAL-BX|ACID5). The firmness level of the apples was determined using a penetrometer, via applying penetration force on the fruit by measuring the force required for a 10 mm diameter probe and 11 mm in height pyramid shape tool to penetrate the flesh of a whole apple, and then computed as kg/cm^2. The surface and flesh damage areas were assessed by image analysis using the Image J package by taking digital photographs, measuring the bruising area in cm^2, and then calculating as bruising (%). The flesh color values were measured by a color difference camera (Konica Minolta, CR-10) by measuring the variation of color values ($L*$, $a*$, $b*$) lightness, red to greenish, and blue to yellowness color ranges, respectively. Moreover, trained panelists also assessed the sensory quality of apples by consuming apple fruit. Panelists (n=10) evaluated a mixed amount of apple slices from the entire treatment periodically. The tasting score for this evaluation ranged from 1 to 5; very high, high, moderate, slightly moderate, and low for each quality level, respectively. These measurements were conducted at the interval of 12 days during the storage period.

Furthermore, means, standard deviation (SD), standard error (SE), etc. were initially assessed by the Microsoft Excel package. The experimental data were then analyzed by Tukey's method using standard IBM SPSS statistic 22, 2013 package, through the one-way analysis of variance (ANOVA) at a 95% confidence level and with the differences at $P< 0.05$ considered statistically significant.

A. Experiment layout, non-destructive samples:

#	TRT	Replication				
1	CT					4
2	CV					4
3	CH					4
4	DCV					4
5	DCH					4
Total		5	5	5	5	20

B. Experiment layout, destructive samples:

TRT	Days after storage							
	12	24	36	48	60	72	84	
CT								28
CV								28
CH								28
DCV								28
DCH								28
	20	20	20	20	20	20	20	140

Table 3-1 Experiment layout, (A) non-destructive samples, (B) destructive samples

4- Result

Weight loss

A considerable decrease in fresh weight loss was observed over the extended storage period from 0 % on arrival to 3.53 % on day 84 of storage. The CT treatment exposed the highest weight percentage followed by The DCV and DCH treatments. The maximum values of 3.28 and 3.26% weight loss were recorded in DCV and DCH treatments, respectively on day 84 of storage (Fig. 3-1). Amazingly, the highest weight loss was observed in CT treatment with a maximum rate of 3.53% on day 84 of storage. The CH and CV treatments, however, on the other hand, revealed the lowest weight loss among the treatments with maximum values of 2.99 and 2.79 %, respectively on day 84 of storage.

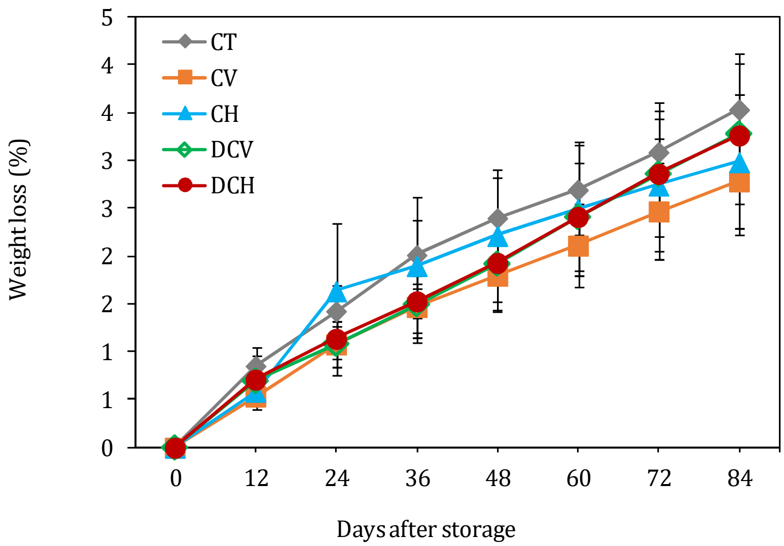

Figure 3-1. Weight loss % during the storage period.

The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05)* and 95 % confidence interval.

Ethylene concentration

Dropping damage and compression on the lateral side of the fruit remarkably affected the ethylene production level and exhibited an increasing trend over the extended storage period. The elevated ethylene production level was observed particularly in CH and DCH treatments. The maximum values of 19.80 and 16.10 ($nLC_2H_4.g^{-1}.h^{-1}$) as the highest ethylene levels were noticed in CH and DCH treatments, respectively on day 84 of storage (Fig. 3-2). The DCV and CV treatments, however, alternatively, revealed the lowest amount of ethylene production levels among the treatments with the maximum values of 8.70 and 10.59 ($nLC_2H_4.g^{-1}.h^{-1}$), respectively on day 84 of the storage period.

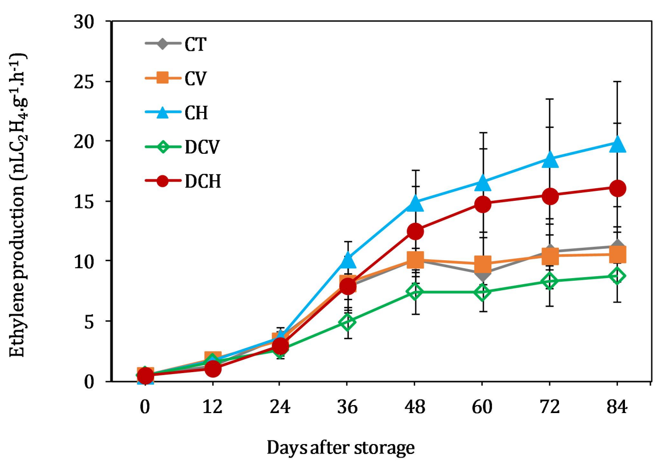

Figure 3-2. Ethylene concentration level during the storage.

The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05)* and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5)

Respiration rate

The respiration rate was higher on arrival with a maximum rate of 8.0 ($nLCO_{2}.g^{-1}.h^{-1}$). Following the arrival, it rapidly decreased while the samples were kept in the cold chamber. The CH treatment revealed the peak level amongst the treatments on day 84 with the maximum value of 2.58, followed by CT treatment with the highest value of 2.52 ($nLCO_{2}.g^{-1}.h^{-1}$), respectively (Fig. 3-3). On the other hand, the least amount of CO_2 was released by DCV and DCH treatments with maximum values of 2.36 and 2.65 ($nLCO_{2}.g^{-1}.h^{-1}$) on day 84, respectively. Elevated respiration rate was expected from the dropped treatments. However, no significant effect of DCV or DCH was observed on the respiration rate during the storage.

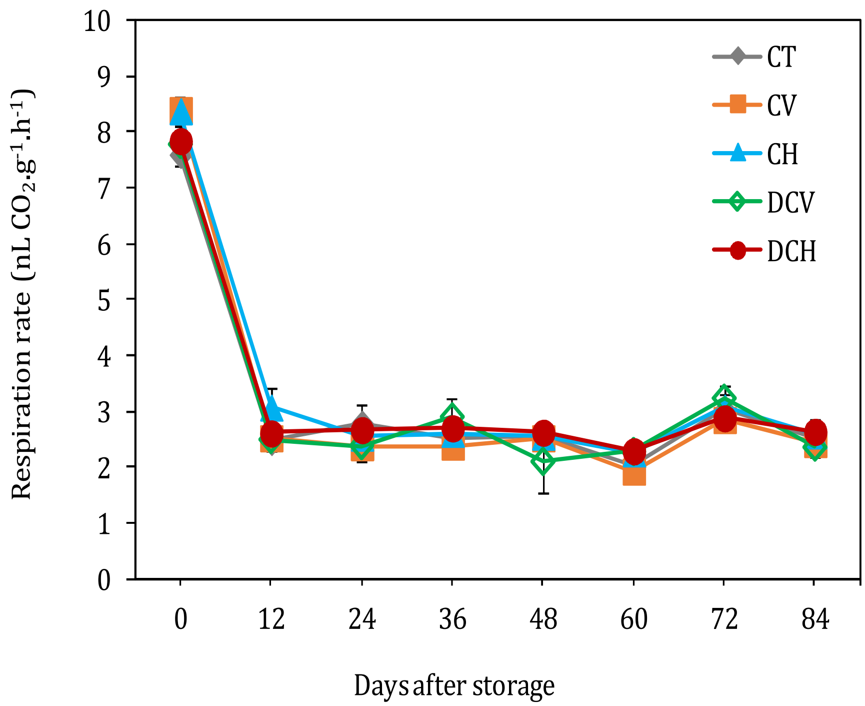

Figure 3-3. Respiration rate during the storage period.

The results were non-significant based on Tukey's method and one-way ANOVA, where ($P>0.05$) and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

5.4. Fruit firmness

The fruit firmness level gradually decreased over the storage period. The DCV and DCH treatments were affected by dropping and revealed the lowest amount of fruit firmness levels among the treatments with minimum values of 2.40 and 2.39 kg/cm^2 on day 84, respectively. However, the CV and CH treatments showed a lower decreasing trend in comparison with the DCV and DCH treatments, with a maximum rate of 2.44 and 2.43 kg/cm^2 on day 84, respectively (Fig. 3-4). On the whole, no significant effect of bruised impact or compression forces was observed in fruit firmness level between treatments.

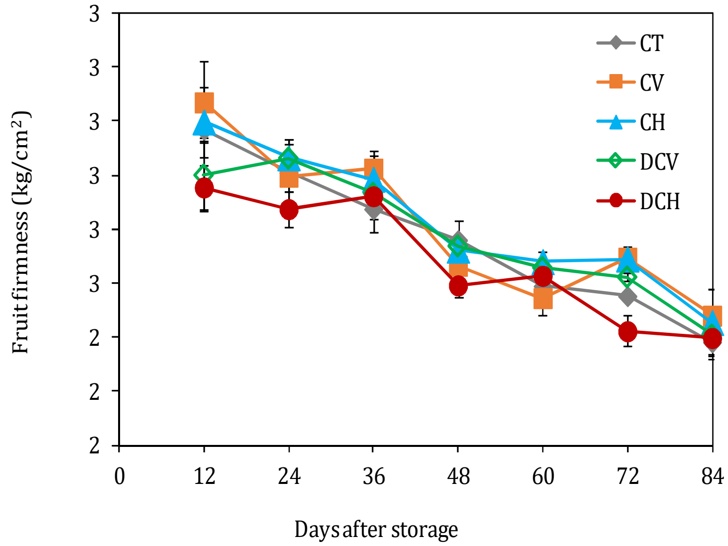

Figure 3-4. Fruit firmness level during the storage period.

The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05)* and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

Sugar content

The total sugar content was slightly enhanced from day 0 and fluctuated over the storage period. The DCH and DCV, and so were the CV and CH treatments depicted slightly increased sugar contents over the extended storage period. The maximum value of 15.45 % SSC content was observed in DCH followed by CV and CH treatments with the maximum values of 15.00 and 14.95 % on day 84, respectively. However, in contrast, the least amount was noticed on DCV treatments, with the highest rate of 14.38 % sugar content on day 84 of the storage period (Fig. 3-5). A higher weight loss % may perhaps cause sugar content to be slightly increased during the storage period.

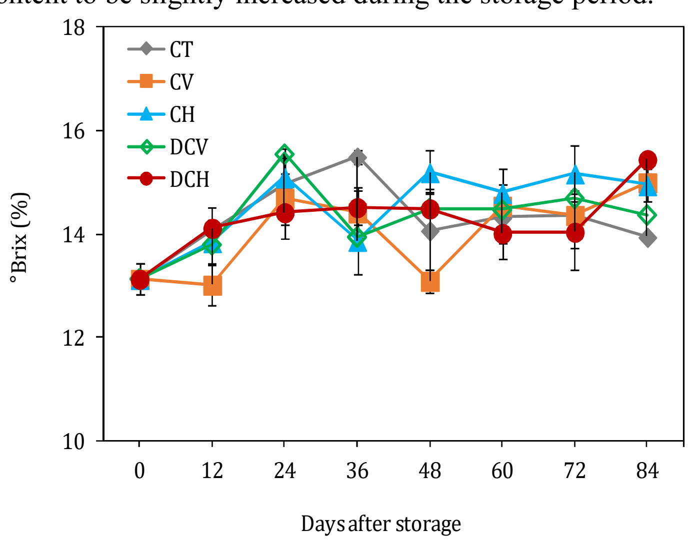

Figure 3-5. The sugar level of apple fruit during the storage period.

The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05)* and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

5.6. Acidity level (%)

The acid concentration of Fuji apple is rare, and it further decreases with the extended storage period. The majority of the treatments showed a 0 % acid level on day 84 of storage. The DCV treatment exposed the maximum value of 0.11 % on day 12, whereas no acidity was found on day 84 of storage. However, on the other hand, the DCH treatment exhibited the minimum rate of 0.04 % on day 84 of storage. Similarly, a decreasing trend was also recorded in CV and CH treatments over the entire storage period. The maximum values of 0.18 and 0.19 on day 12 were found on CV and CH treatments, respectively, while no acidity was noticed on day 84 of storage (Fig. 3-6).

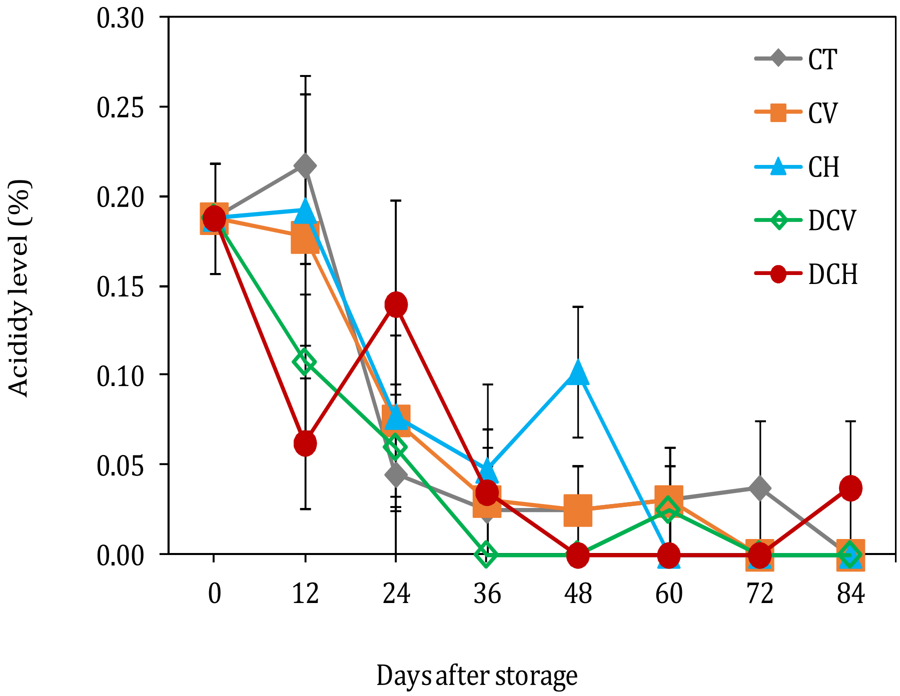

Figure 3-6. Acidity level % of apple fruit during the storage period.

The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05*) and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

Flesh color values (L a* b*)*

The flesh color values showed variation over the storage period in the (*L*, a*, b**) color range. The *L**, which describes the lightness level (the darkest and the lightest) point, exhibited a slightly increasing trend particularly in DCH and CH treatments with the maximum values of 79.95 and 79.80, *L** color range, respectively on day 84 of storage. (Fig. 3-7, a). The DCV and CV treatments, however, had variation, but the maximum values of 79.25 and 79.08 (*L**) color range, respectively were observed on day 84 of storage.

The red-to-greenish color range (*a**) value, on the other hand, showed a decreasing trend. The minimum intensity of 2.37 and 2.20 in DCV and DCH, respectively were found on day 84 of storage (Fig. 3.7, b). No significant effect of dropping or compression forces was observed in (*a**) value color range over the extended storage period.

However, the blue to yellowness (*b**) color series had variations over the extended storage period. The maximum value of 21.63, with a minimum of 19.28 (*b**) color range in DCV, whereas the maximum and minimum values of 19.93 and 19.75, respectively, on days 12 and 84 of storage were recorded on DCH treatment (Fig. 3-7, c). No significant effects of damage impact or compression forces were noticed in the blue-to-yellow color range during the storage.

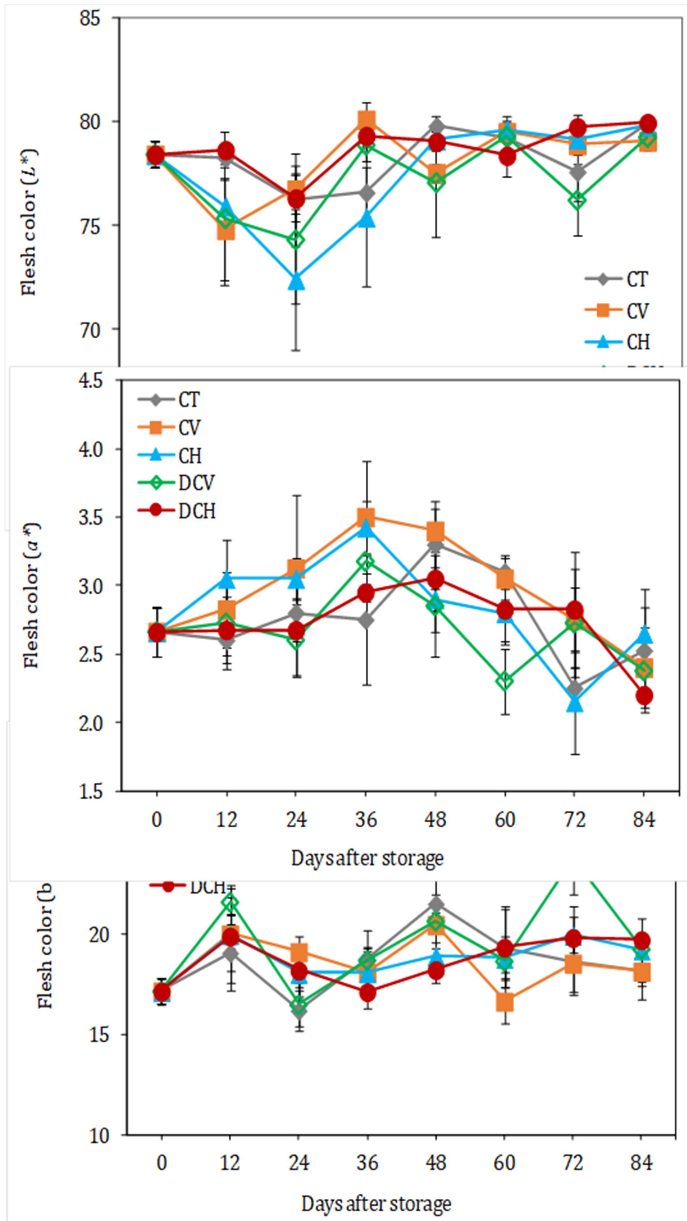

Figure 3-7. Flesh color values, A: *L, B: *a**, C: *b** during the storage.**

The results were non-significant based on Tukey's method and one-way ANOVA, where ($P>0.05$) and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

Surface and flesh bruised areas

The surface damage area caused by dropping was slightly expanded particularly in DCV and DCH treatments. The DCH treatment depicted an increased bruising area with a maximum value of 34.00 % on day 84. However, the DCV exhibited a lower increasing trend with the highest value of 33.67 % on day

84 of storage (Fig. 3-8, a). On the whole, an average of 2.70 and 3.17 % increased surface bruised area in DCV, and DCH treatments respectively were found over the entire storage period. No bruising incidence was reported on CV and CH treatments.

Dropping damage also affected flesh bruising and was increased. The textural bruised area in DCV and DCH treatments increased by extending the storage period. On the contrary with surface damage, the DCV treatment showed increased flesh damage area over DCH. The maximum values of 12.87 and 11.07 % flesh bruising area were noticed in DCV and DCH treatments, respectively on day 84 of storage (Fig. 3.8, b). Overall, an average of 3.50 and 2.25 % increased flesh bruised area were recorded in DCV and DCH treatments during the storage.

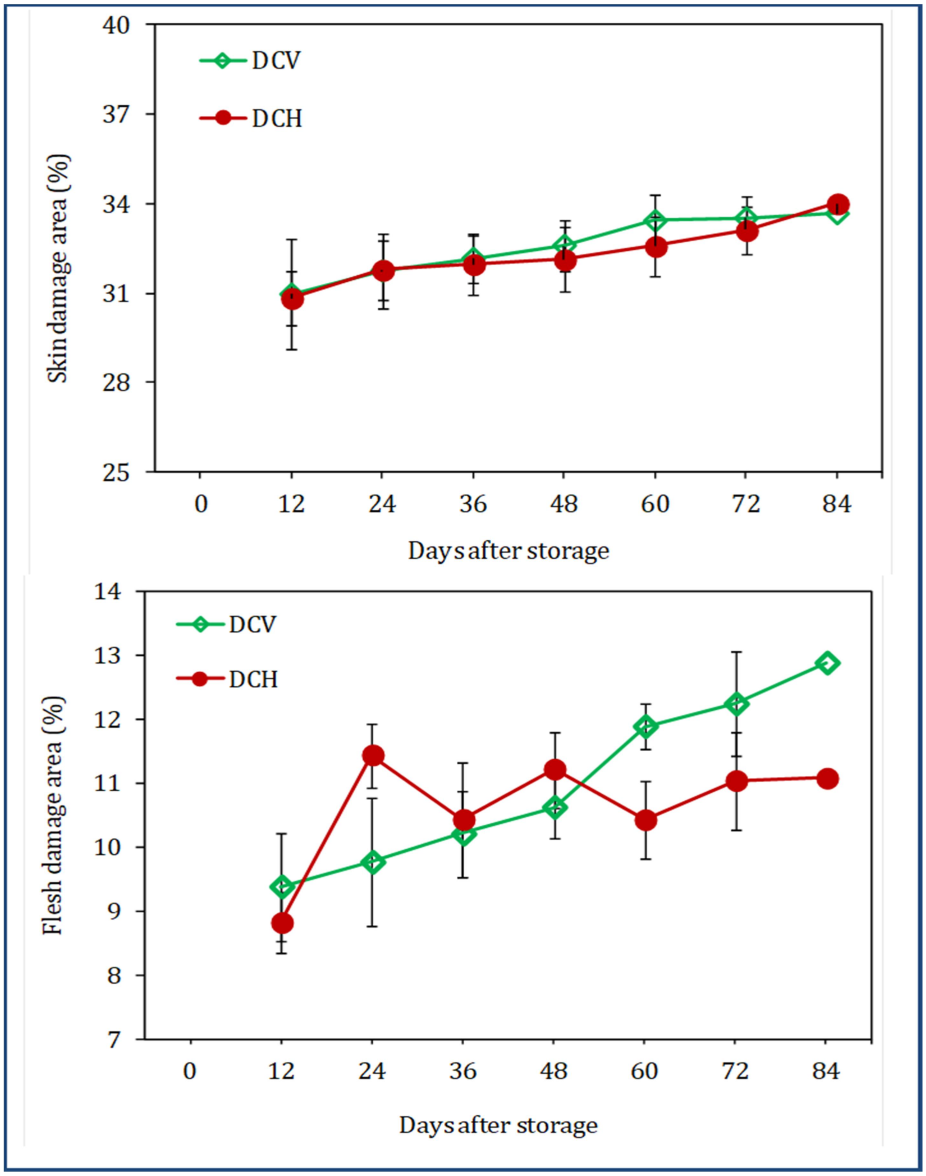

Figure 3-8. Fruit damage area, A: surface bruise area, B: flesh bruise area. The results were non-significant based on Tukey's method and one-way ANOVA, where (*P>0.05*) and 95 % confidence interval. Vertical bars represent (SE) of the mean (n=5).

5.9. Quality evaluation by respondents

The consumer's perception of quality attributes indicated variation. However, on the whole, according to the hedonic skill test, respondents perceived the quality attributes perhaps slightly decreased. The sugar content had a decreasing trend from a 3.93 tasting score on arrival to 3.17 on day 84 of storage. The respondents also marked a decreasing trend in acidity level from 3.93 on arrival to 3.0 tasting score on day 84 of storage. Similarly, the juice level also marked a gradual decline by respondents. The highest and the lowest values of 4.0 and 3.67 tasting scores respectively were noticed on arrival and 84 days of storage period. The firmness level exhibited remarkable reduction, with the maximum, and minimum values of 4.07 and 2.92 tasting scores on arrival and day 84 of storage, respectively. The crispness value of the fruit also showed a decrease from 4.36 on arrival to a 3.08 tasting score on day 84 of storage (Fig. 3-9).

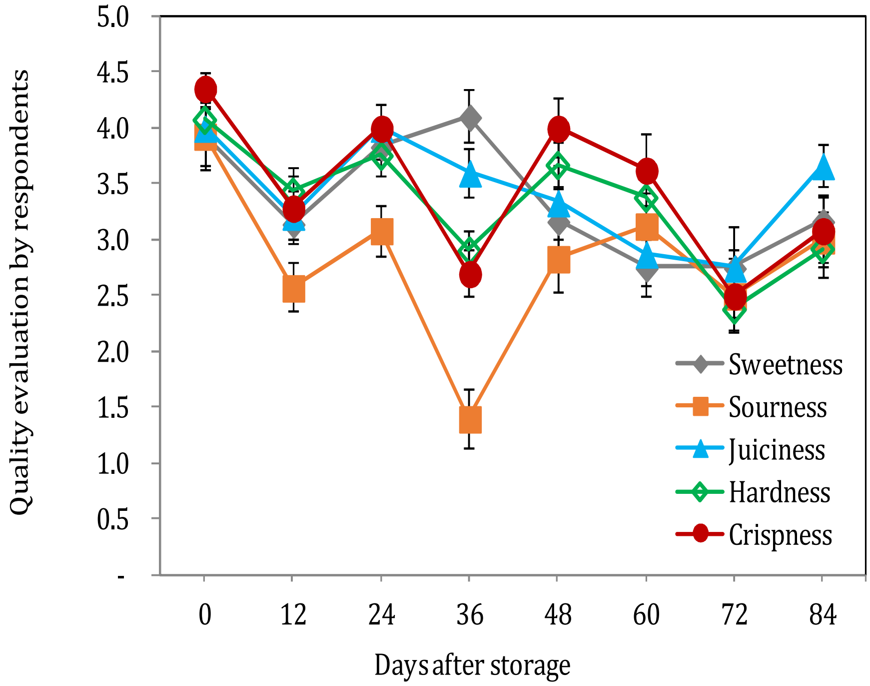

Figure 3-9. Respondent's preference on quality during the storage.
The vertical bars represent (SE) of the mean (n=5).

5. Discussion

Fruit fresh weight showed a declining trend over the extended storage period. The CT treatment revealed the highest percent weight loss amongst the treatments with a maximum value of 3.53 % on day 84 of storage. We did not observe any possible reason for the increase in weight loss in CT. Previously we conducted a similar experiment on cherry fruit quality parameters and the CT treatment revealed almost the highest weight loss % between treatments. The DCV and DCH treatments also exhibited relatively higher weight loss % with maximum values of 3.28 and 3.26 %, respectively on day 84 of storage. No significant increase in percent weight loss on DCH was observed over DCV. Either the DCV or DCH treatments showed almost the equivalent amount of weight loss % over the extended storage period. No significant effect of lateral compression force was found on DCH treatment. Meanwhile, the least amount was recorded on CV and CH treatments with the maximum rates of 2.79 and 2.99 %, respectively on day 84 of storage. The CH treatment exposed slightly enhanced percent weight loss than the CV; presumably caused by the effect of lateral compression force. The weight loss in fruit depends on the structure of the skin and the nature of waxes on the surface of the fruit [31]. The moisture loss decreases the visual quality and contributes to the loss of turgor pressure and subsequent softening [32].

Dropping damage and compression on the lateral side progressively enhanced the ethylene production level. The elevated ethylene production level was observed particularly in the CH and DCH treatments. The CH treatment produced the highest ethylene level of 19.81($nLC_2H_4.g^{-1}.h^{-1}$), followed by the DCH with the maximum value of 16.10 ($nLC_2H_4.g^{-1}.h^{-1}$) on day 84 of storage, respectively. The lateral compression and dropping damage further affected the fruit and exhibited an increased ethylene production level (Fig. 3-2). Interestingly, the CV and DCV treatments exhibited the least amount of ethylene concentration with maximum values of 10.59 and 8.77 ($nLC_2H_4.g^{-1}.h^{-1}$), respectively on day 84 of storage. Even though the DCV and CV were dropped before storage and compressed during the storage period, they released the least amount of ethylene production. We could not find any possible reason for the reduction of ethylene in DCV and CV. However, certain possibilities exist. The first possibility is the physiological differences between the selected samples for this treatment may cause decreased ethylene production. The second possibility is the leakage of the containers or jars in which samples were kept for incubating ethylene gas. However, it could not be the same way with the four replications. The third possibility is the relatively lower temperature during the storage, which slowed the ethylene-releasing process, but it is in contradiction with the other treatments, the entire treatments were kept under similar storage conditions. Plants produce ethylene, but only ripening climacteric fruit and diseased or wounded tissue produce it in sufficient amounts to affect adjacent tissue [33]. Ethylene is a natural ripening agent that strongly affects the growth, development, and shelf-life of fruits, vegetables, and ornamental crops [34]. Plants and fresh products directly release it, and it is already effective at very low concentrations, ranging from 10 ppm to 10 ppb, depending on the target [35].

The respiration rate revealed a relatively enhancing trend on arrival at ambient temperature. Fruit exposure to relatively higher temperatures releases elevated CO_2 levels. This trend is expected as the temperature has been identified as the most important factor influencing the respiration behavior of the fruits [36]. The highest amount of CO_2 rate were recorded in CV and CH treatments with the maximum values of 8.40 and 8.36 ($nLCO_2.g^{-1}.h^{-1}$), respectively. However, following the arrival, it rapidly decreased to a greater level after the samples were kept in the cold storage and remained almost unchanged throughout the entire storage period, presumably caused by lower temperature which slowed the CO_2 release. The DCH and CH treatments slightly showed elevated respiration rates, with maximum values of 2.65 and 2.58 ($nLCO_2.g^{-1}.h^{-1}$), respectively on day 84, most probably, because of the effect of lateral compression force and enhanced ethylene level, which provoked slightly higher respiration rate (Fig. 3-3). Wounding plant cells and tissues causes the respiration rate to increase [37]. No significant effect of ethylene production was observed in the respiration rate. However, the DCV and CV treatments, on the other hand, had variations in respiration rate and showed the least amount during storage. No significant effects of DCV or DCH were observed in the respiration rate. The lower temperature perhaps affected the respiration rate to be decreased.

The fruit firmness level gradually decreased during the storage period and reached its lowest level 84 days after storage. Elevated ethylene production may affect softening and contribute to a loss of firmness. On the whole, an average of 12.6 % decrease was observed in the entire treatment during the storage. The dropping damage and lateral compression forces somewhat affected the apple firmness level. Presumably caused by bruised impact and lateral compression force. The DCH treatment exhibited a slightly decreased firmness over the DCV with a minimum value of 2.39 kg/cm^2. Similarly, the CH treatment revealed a slightly declined firmness level over the CV treatment, yet again it perhaps attributed to the horizontal compression which may induce lateral cells to be affected by the weight pressure. In turn, ethylene which was provoked by bruised impact and led to increased respiration rate may perhaps cause the fruit firmness level to be decreased. However, it is reported that although ethylene production of apples was associated with increased maturity, fruit firmness was not necessarily related to ethylene production [8]. Softening is generally considered an undesirable ripening process in apple fruit, as firmer apples tend to be juicier, crisper, crunchier, and less mealy than softer fruit [38].

The sugar content of the stored apple slightly increased from day 0 and fluctuation during the storage period. The increasing trend presumably caused by the conversion of starch into simple sugars, or a decrease in the fresh weight of the fruit influenced by respiration rate also could affect sugar content to be increased. However, as illustrated in (Fig.3-5), dropping damage and compression forces were not primarily considered to be affected by sugar content. On the whole, an average of 13.14 % SSC content was recorded on arrival. Following the arrival, it slightly increased and reached 14.75 on day 84 of storage. No significant effect of DCV or DCH was observed in sugar content. The total soluble solids increase during storage for 150 days [39], because the starch to sugars conversion continues even during storage [40]. The DCH treatment exhibited the highest peak maximally of 15.45 % among the treatments. The DCV exhibited a slightly decreased, maximum value of 14.38 % SSC on day 84 of storage, respectively. However, no significant variation was noticed between CV and CH treatments.

The acidity level of the Fuji apple is scarce. Over the storage period, we observed a gradual decline in acidity level. The titratable acidity of the fruit depends on the rate of metabolism especially respiration which consumes organic acid and thus declines acidity [40]. The maximum values of 0.11 and 0.06% were found on day 12 over DCV and DCH treatments, respectively, whereas, this range significantly declined, no acidity percent was observed in DCV treatment on day 84, while 0.04 % acid level was noticed on DCH treatment. Similarly, almost identical trends were observed in CV and CH treatments with the maximum values of 0.18 and 0.19 % acidity on day 12 of storage. However, no acidity concentration was noticed on day 84 of storage in the CV or CH treatments, respectively. The fruits are living organs that respire even after harvest from the tree and during storage which consumes the organic acids [41]. Despite establishing an optimal storage environment, fruits, including apples, tend to decrease quality attributes. However, besides controlling the storage condition, it could only be maintained to an acceptable level by reducing the bruising impact over the chain of post-harvest.

It should be noted that no significant effect of bruised impact and compression forces was found in the acidity level. The reductions in acidity may also be correlated with the respiration rate which consumes organic acid and thus declines acidity level.

We observed variations in flesh color values. The ($L*$) color range had enhancing trend in lightness level, it showed a slight increase from 75.35 and 78.65 on day 12, to 79.25 and 79.95 lightness levels on day 84 of storage on DCV and DCH treatments, respectively (Fig. 3-7, a). No effect of bruising impact was found in the lightness level. This may be attributed to the relatively lower temperature of the storage, which maintained the lightness level almost unchanged. The CV and CH treatments also experienced slightly increasing trends over the storage period. However, on the other hand, the ($a*$) color range which is portrayed in (Fig. 3-7, b), showed a slightly declining trend from a red to greenish color range throughout storage. The DCV and DCH treatments tended from the red to the greenish color range. The maximum values of 2.73 and 2.68 on day 12, while, the minimum of 2.65 and 2.38 on day 84 were observed in DCV and DCH treatment, respectively. It should be noted that the DCH treatment showed a further decrease over DCV which is ascribed to the lateral compression force applied during the storage. However, the CV and CH had variations. Similarly, the (b^*) blue to yellowness color range as illustrated in (Fig. 3-7, c) had also reduced from the yellow to blue range. The DCV and DCH treatments exposed a slightly decreasing trend. Its minimum of 19.28 and 19.75 (b^*) color range were recorded on day 84, respectively. Likewise, the CV and CH treatments also revealed a slight decline over the storage period. The (L^*, a^*, b^*) color space is device independent, providing consistent color regardless of the input or output devices such as digital camera, scanner, monitor, and printer [42]. Although internal appearance and defects (e.g., physiological disorders, bruising, rots) cannot be evaluated at the time of purchase, they affect consumers' quality perception and their willingness to purchase or consume [43]. In general, no significant effect of bruised impact and compression forces were observed in (L^*, a^*, b^*) color values during the storage period.

The surface bruising area resulting from the free dropping slightly increased along with the increase in the storage duration. The Fuji apple is a darker-colored variety usually having a red peel on which bruises are difficult to identify [44]. However, it did not show a significant increase. The skin damage area was only observed in DCV and DCH treatments. Caused by dropping and revealed slightly enhancing trends. The DCH treatment exhibited a bruising area to be expanded over the DCV, although, the DCV treatment itself demonstrated a relatively higher damage area on day 12 over DCH. However, on day 84, the DCH treatment showed an increased bruising area over the DCV treatment. A maximum of 34.00 and 33.67 % surface bruising area were noticed in DCH as well as DCV treatments on day 84, respectively. The CV and CH treatments did not exhibit any surface bruising incidence during the entire storage period. Bruise damage from harvesting, handling, transporting, and sorting of fruit has been identified as a major source of reduced fruit quality, resulting in loss of profits for the entire fruit industry [45]. The three factors that can physically cause fruit bruising or impact, are vibration, and compression load [46].

Furthermore, the flesh bruise area caused by dropping damage also expanded. The DCV treatment showed slightly increased flesh bruising than the DCH treatment, with maximum values of 12.87 and 11.07 %, respectively, on day 84 of storage. We did not observe any sign of bruising in the flesh of the CV and CH treatments. The impact damage which resulted in a bruise on the surface as well as in the flesh part did not show a significant expansion, perhaps because of the relatively thicker skin layer, tough and firm texture, and lower temperature presumably contributed to reducing rapid diffusion of damaged areas.

It is commonly believed that a diet rich in fruit and vegetables helps in preventing certain diseases including some types of cancer. The consumer started to choose products that are appropriate in terms of not only the sensory properties (taste, smell, appearance) but also nutritional attributes (content of polyphenols, vitamins, and minerals)[30]. Based on the apple hedonic quality test, a gradual decrease in selected quality characteristics was found. The sugar content showed a slight decrease which is contrary to experimental data. The experimental data indicated a slight increase in soluble solid content (SSC). The acidity and firmness levels revealed a somewhat decline, as perceived by the respondents, which is by the experimental data. Similarly, the juice level also marked a slightly decreasing trend over the storage period; it may be caused by the effect of respiration which affected weight loss. Consumer's perception varies depending on their preferences regarding sensory quality characteristics. However, sensory quality attributes such as acceptable sugar or acid ratio, firmness, juice, and color are the priority concerns given to almost all consumers when making a purchasing decision.

6. Conclusion

The results of the present work indicate that physical damage such as bruising impact and compression forces affected apple quality and led to undesirable physiological changes. Bruising caused by dropping provoked elevated ethylene concentration which affected respiration rate and weight loss. Apple as a climacteric commodity while exposed to bruised impact, produce relatively higher ethylene level. Increased ethylene was observed in CH and DCH treatments which gradually affected fruit firmness level. The surface and flesh bruised areas were expanded and affected by dropping. Similarly, the sugar content increased from day 0 and had fluctuation and remained almost unchanged. The respiration rate induced by ethylene may be affected by acidity level and showed a gradual declining trend. The flesh color values revealed variation, no significant effect of bruised impact was observed in flesh color values.

Furthermore, Besides the detrimental effect of bruised impact which leads to physiological disorders and loss of quality, the experiment result also revealed a substantial effect of lateral compression force in comparison to the vertical compression stresses in apple fruit quality parameters. The lateral compression further affected the quality attributes than the vertical compression. We found out that under the lateral direction apple is less strong to physical stresses and was affected more which increased bruised impact and other physiological disorders. However, under the vertical orientation, the apple is extra strong and can withstand stresses, cannot easily bruise, and tolerate more pressure during handling and other rough post-harvest operations. Therefore, it is strongly suggested that during packing, handling, transport, and storage operations besides avoiding overfilling, dumping, and stacking the package, the apple should be kept to its vertical orientation rather than the lateral sides. In this direction, the bruises and other stresses that occur particularly during handling, could significantly decrease.

Therefore, proper harvesting and post-harvest handling practices are the primary concerns to take into consideration in Afghanistan. Establishing post-harvest facilities, such as processing centers, local and typical storage facilities, and market infrastructures is necessary for decreasing losses and maintaining quality and shelf life.

7. Recommendation

We further suggest proper care during harvesting by skilled laborers and improve awareness of the farmer community with the utilization and distribution of proper harvesting and post-harvesting tools, and improved and feasible extension services. Besides education of the farmers and other involved post-harvest actors, heavy investment through a deep investigation of the post-harvest situation along with the establishment of sustainable infrastructure in fruit markets, as well as in apple production areas is urgently needed if the aim is to decrease the losses, maintain quality, stabilize price variations, and extend availability and storage life.

The utilization of suitable packing materials, avoiding dumping and overfilling the packages, proper transportation systems, avoiding overloading, and considering cool chain during transport with proper cargo load mainly in long distances. The establishment of packing houses, market infrastructure, and suitable storage facilities where fruit could be stored for an extended period, are critically important issues to be taken into consideration.

8. Acknowledgments:

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