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# STORAGE PERFORMANCE OF APPLE CULTIVARS HARVESTED AT DIFFERENT STAGES OF MATURITY

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## ABSTRACT

The experiment was conducted to study the effect of storage on quality parameters of apple cultivars harvested at different stages of maturity at Horticulture Postharvest Laboratory, KP Agricultural University, Peshawar-Pakistan during 2007-08. The fruits were harvested at three different stages of maturity at fifteen days interval representing early, mid and late harvesting stage from apple cultivars: Royal Gala, Mondial Gala, Golden Delicious and Red Delicious and evaluated for different quality parameters at 0 and 150 days storage at 5±10 $^0$C with 60-70 % relative humidity. Cultivar Red Delicious had the highest ascorbic acid (12.49 mg/100g), firmness (5.85 kg/cm$^2$) but also the bitter pit (14.22 %) and soft rot (15.52 %) incidence, while titratable acidity (0.56 %) was observed in cultivar Mondial Gala. The percent weight loss, total soluble solids, total sugar, bitter pit incidence and soft rot increased while, juice content, titratable acidity, ascorbic acid and firmness declined with increase in storage duration. The juice content (47.68 %), total soluble solids (10.07), total sugar (9.31 %), ascorbic acid (10.11 mg/100g) and soft rot (9.52 %) recorded with early mature fruit, increased to juice content (59.33 %), total soluble solids (12.92), total sugar (12.98 %), ascorbic acid (12.50 %) and soft rot (15.22 %) accordingly in late mature fruits, while weight loss (3.34 %), titratable acidity (0.59 %), firmness (5.88 kg/cm$^2$), and bitter pit (11.69 %) recorded at early maturity stage, declined with delaying the harvesting to weight loss (1.93 %), starch score (3.21), titratable acidity (0.49 %), firmness (4.81 kg/cm$^2$), density of fruit (4.81 g/cm$^3$) and bitter pit (6.63 %) at late maturity stage.

**Keywords:** Apple, cultivars, storage, harvesting stage, weight loss, ascorbic acid, firmness, bitter pit, soft rot.

## INTRODUCTION

Apple (*Pyrus malus*) is an important fruit desired for taste and nutritive value (Bokhari., 2002). Apple is cultivated in the northern and hilly areas of Pakistan (Ali *et al*., 2004; Bokhari., 2002) over an area of 11.13 thousand hectares with a total production of 437.39 thousand tons (MINFA, 2008-09). The energy, carbohydrates, fat, protein and fiber contents were high in Golden delicious variety while moisture in Kala kulu and the ash contents were high in Red delicious (Mukhtar *et al.,* 2010). The apple fruit is in high demand through out the year and hence a considerable quantity is generally stored in cold storages in Pakistan. Apple being a perishable commodity is prone to qualitative and quantitative losses after harvest. The losses may occur during postharvest operations or storage which could be as high as 17% (Shah *et al.,* 2002) or even greater (Ilyas *et al*., 2007). The postharvest quality and losses in apple fruit may depend on cultivar (Saleh *et al.,* 2009), cultural practices (Tomala, 1999), nutritional status (Hernandez *et al.,* 2005), harvesting stage (Vielma *et al*., 2008) and storage conditions (LeBlanc *et al.,* 1996). The storage life of apple can be increased and post harvest losses decreased by selecting the best adopted cultivars, provision of optimum nutrition and harvesting at optimum stage (Strief, 1996). In Pakistan, the apples are harvested at edible maturity for both fresh market and storage. Fruit harvested at this stage are more prone to mechanical injury, have short storage life and greater susceptibility to pathogens and physiological disorders (Hribar *et al*., 1996). In addition, careless harvesting characterized by immature and over mature fruit, is another serious cause of post harvest losses (Ingle *et al*., 2000). Being a climacteric fruit, the apple can be harvested at physiological maturity, stored and ripened artificially to catch good price in the market. In general, apple fruit harvested at immature stage have poor colour and flavour and can be more susceptible to physiological disorders such as bitter pit and superficial scald (Juan *et al*., 1999). By contrast, fruit harvested over-mature tend to be soft and easily damaged during post harvest operations (Hribar *et al*., 1996). Such fruits are more susceptible to diseases and physiological disorders as well as quality deterioration during or after storage (Lafer, 2006). A wide range of indices has been tested over many years as possible indicators of harvest maturity (Lau, 1985). Ethylene production and starch content have been commonly used to predict the maturity of apple fruit (Lau., 1985) but relationships between ethylene production and optimum harvest dates can be poor, and the timing of increased ethylene production is a function of cultivar as well as growing region, orchard within a region, cultivar strain, growing season conditions, and nutrition (Watkins, 2003). The problem is further complicated by the fact that several different cultivars are grown in Pakistan which may vary considerably in their time of maturity and storage performance (Drake *et al*., 2002). While the genetic characteristics of the apple fruits for storage may vary, yet optimal storage may retain good organoleptic quality longer than suboptimum storage conditions (Sestras *et al*., 2006). Therefore, the present research was carried out to identify the optimum harvest stage in apple cultivars for maximum fruit quality and storage life and minimize post harvest losses in apple.

## MATERIALS AND METHODS

The fruits were harvested at three different stages of maturity at fifteen days interval representing early, mid and late harvesting stage from four apple cultivars: Royal Gala, Mondial Gala, Golden Delicious and Red Delicious. Healthy trees of uniform size and good vigour were selected for harvesting fruit samples. Fruit showing the symptoms of surface damage or abnormalities were discarded while fruits of uniform size were selected for the study. The fruits harvested at each stage from different cultivars were divided into two groups each containing 50 fruits. One lot was analysed for different quality attributes while the other was shifted to cold storage and stored for 150 days at 5±1 $^{0}$C and 60-70 % relative humidity.

The data were recorded for the following post harvest quality parameters at 0 and 150 days of storage.

**Weight loss (%):** Five fruits in each treatment were separated for weight loss test. The initial weight of each fruit was noted with the help of electronic balance. The weight loss (%) was calculated as under:

$$\text{Fruit weight loss (\%)} = \frac{\text{Initial weight - final weight}}{\text{Initial weight}} \times 100$$

**Percent juice content:** Juice was extracted from five randomly selected fruit from each treatment with the help of juice extracting machine, weighed and the percentage was computed as described by Rehman *et al*., (1982).

$$\text{Percent Juice} = \frac{\text{Weight of juice fruit}^{-1}}{\text{Average weight of fruit}} \times 100$$

**Total soluble solids ($^{0}$Brix):** Total Soluble Solids of the fruit was determined at 0 and 150 days storage accordingly. Total soluble solids (TSS) were measured with a hand refractometer (Kernco, Instruments Co. Texas).

**Total sugars:** Reducing and non-reducing sugars was determined by the method as described in A.O.A.C (1990).

**Percent acidity:** Acidity was determined by neutralization reaction (AOAC, 1990)

**Ascorbic acid (mg/ml):** Ascorbic acid was determined by the standard method as reported in AOAC (1990).

**Fruit firmness (kg/cm$^2$):** Data pertaining to fruit firmness was recorded with the help of penetrometer (Effigi, 11mm Prob.) for five fruits per treatment (Pocharski, *et al.,* 2000).

**Bitter pit (%):** Percent bitter pit incidence was observed visually in each treatment by calculating the surface area of each fruit covered with the symptoms of bitter pit at time 0 and 150 days of cold storage.

**Soft rot (%):** Percent soft rot in each replication of treatments was examined visually and counted during 150 days storage and their disease percentage of fruits was calculated by formula as under

$$\text{Disease incidence (\%)} = \frac{\text{Number of diseased fruits}}{\text{Total number of fruits}} \times 100$$

**Statistical Analysis:** The data were analyzed by using completely randomized design (CRD) with twenty four treatment combinations replicated three times and means were further assessed for differences through Least Significant Difference (LSD) test. Statistical computer software, MSTATC (Michigan State University, USA), was applied for computing both the ANOVA and LSD (Steel and Torrie, 1980).

## RESULTS AND DISCUSSION

**Weight loss (%):** Moisture loss from the fruits is serious consideration which decreases the visual quality and contributes to the loss of turgor pressure and subsequent softening (Vander-Beng, 1981). The maximum weight loss (2.83 %) recorded in cultivar Golden Delicious which was significantly higher than Royal Gala (2.43%), Red Delicious (2.42%) and Mondial Gala (2.35%), with the difference in weight loss in the later three cultivars being non significant. The mean percent weight loss increased significantly with storage for 150 days to maximum of 5.02 %. The maximum weight loss (3.34 %) was recorded in early harvested fruits, significantly higher than both mid and late harvesting stages. The interaction effect of cultivars and storage duration was also significant. The maximum weight loss (5.67 %) was recorded in cultivar Golden Delicious after 150 days storage while it was 4.85 and 4.70 % in cultivars Royal Gala, Red Delicious and Mondial Gala respectively. The difference in the later three cultivars was, however, non significant. The interaction of cultivars and harvesting stages significantly affected percent weight loss. The maximum weight loss (3.73 %) observed in cultivar Golden Delicious at early harvesting stage. The weight loss tends to decline with advancing harvesting stage so that the minimum weight loss (1.77 %) recorded in Red Delicious at late harvesting stage. The interaction of storage durations and harvesting stages also significantly affected the weight loss. The maximum weight loss (6.67 %) recorded at early harvesting stage after 150 days storage. The interaction effect of cultivars, storage durations and harvesting stages was also significant on weight loss. The maximum weight loss (7.45 %) was observed in cultivar Golden Delicious at fruits harvested at early stage with storage of 150 days (Fig. 1). Apple cultivars vary significantly in weight loss (Veravrbeke *et al*., 2003). The mean weight loss was the highest in Golden Delicious followed by Royal Gala, Red Delicious and Mondial Gala. The rate of moisture from the fruit depends on skin thickness and nature of surface waxes (Veravrbeke *et al*., 2003), which may vary considerably in different apple cultivars or even in same cultivar in different years of production (Homutova and Blazek, 2006). Since, cultivar Red Delicious is characterized by a thicker waxy layer, (Veraverbeke *et al*., 2001), it may lose less moisture. Harvesting stages also significantly affected the weight loss. Generally, the weight loss in fruit harvested at early mature stages was significantly higher than both mid and late harvesting stages, while the difference in mid and late harvesting stages was non significant. Since, the weight loss in fruit depends on moisture loss (Ghafir *et al*., 2009), which is regulated by epi-cuticular waxes which increase with maturation (Lau, 1992). The high weight loss in fruit harvested at early stage of maturation may be due to poorly developed waxy surface and cuticle (Ihabi *et al*., 1998; Sass and Lakner, 1998). It may explain relatively lower weight loss in late harvested fruits that have fully developed waxy layer on their surface (Lau, 1992). The percent weight loss increased significantly with storage for 150 day. The moisture and subsequent weight loss in fruits generally increased with increase in storage duration (Tu *et al*., 2000).

**Juice content (%):** The juice content of apple fruit depends on water present in the fruit (Allan *et al*., 2003). The apple cultivars varied significantly in juice content with the maximum juice content (58.54 %) was recorded in Red Delicious. The minimum juice content (52.04 %) was recorded in Royal Gala, followed by Golden Delicious and Mondial Gala with 52.43 and 54.40 % respectively. The juice content significantly decreased from 61.28 % for fresh harvested fruits to 47.43 % for fruits with 150 days storage. The harvesting stages also significantly affected the percent juice content of apple cultivars. Juice content increased from the minimum of 47.68 to 56.05 % and finally to the maximum of 59.33 % with harvest at early to mid and late stages of maturity respectively. The difference in juice content of mid and late harvested fruit was, however, non significant (Table 1). The juice content of fruit was the maximum in cultivar Red Delicious but the minimum in Royal Gala. Since cultivar Red Delicious had the minimum weight loss, thus, it is likely to have high juice percentage. The mean juice content of the fruit also related to harvesting stages and tended to increase with delaying in harvesting late stages. The juice content of apple fruit depends mainly on the water content and its loss from the fruit. Thus, cultivars characterized by more weight loss are generally less juicy (Dzonova *et al*., 1970). This will explain the decrease in percent juice with increasing storage duration (Allan *et al*., 2003).

**Total soluble solids:** The total soluble solids were significantly increased during storage, it from 10.02 for fresh harvested fruit to 12.95 for 150 days storage. Harvesting stages significantly affected the total soluble solids. The minimum total soluble solids (10.07) at early harvesting stage increased with harvesting at mid mature stage (11.47) and finally to the maximum of 12.92 at late harvesting stage (Table 1). The interaction of storage durations and harvesting stages also significantly affected total soluble solids. The maximum total soluble solids (13.99) was recorded at late harvesting stage after 150 days storage while the minimum total soluble solids (8.28) was recorded at 0 day storage at early harvesting stage (Fig. 2). Total soluble solids of apple and other fruits is a major quality parameter which is correlated with the texture and composition (Weibel *et al*., 2004; Peck *et al*., 2006). While Ali *et al*., (2004) reported significant variations in their TSS, acidity and other physico-chemical characteristics in apples harvested from different varieties but no significant variations were observed in total soluble solids of different cultivars in this study. The total soluble solids increased during storage for 150 days (Rivera, 2005). Since the starch content decline during storage (Table 1), it is likely to observe increased TSS (Crouch, 2003). Similarly, the hydrolysis of complex cell wall polysaccharides into simple sugars could be another pool responsible for increased TSS with storage (Ben and Gaweda, 1985). The interaction effect revealed that the percent increase in TSS was 30.51% in fruits harvested at early stages, but 23.56 and 15.02 % in fruits harvested at mid and later stages of harvest. It may due to more starch content in fruit harvested at early mature stages as compared to fruits harvested at mid or late mature stages (Table 1) and hence more conversion in early harvested fruits.

**Total sugar (%):** The sugar content is one of the major characteristics of fruit quality and market value. The total sugar increased during storage from 9.67 % for fresh harvested fruit to 12.47 % in fruit stored for 150 days. The total sugar increased significantly with delayed harvesting stages from the minimum total sugar (9.31 %) at early harvesting stage, followed by mid and late harvesting stages with 10.89 and 12.98 % respectively (Table 1). The interaction of storage durations and harvesting stages also significantly affected total sugar. The maximum total sugar (14.04 %) recorded at late harvesting stage after 150 days storage while the minimum total sugar (7.63 %) observed at early harvesting stage after 0 day storage (Fig. 3). Generally, there are significant variations in their TSS, acidity and other physico-chemical characteristics in apples harvested from different varieties (Ali *et al*., 2004) but no significant variations were observed in total soluble solids of different cultivars in this study. The total sugars increased during storage (Rivera, 2005) because starch is hydrolyzed to sugars at edible maturity (Magein and Leurquin, 2000). The starch to sugars conversion continue even during storage (Beaudry *et al*., 1989), resulting increase in total sugars with storage duration (Crouch, 2003). Since the starch content decline during storage (Table 1), it is likely to observe increased TSS, predominantly sugars (Crouch, 2003). Similarly, the hydrolysis of complex cell wall polysaccharides into simple sugars could be another pool responsible for increased TSS with storage (Ben and Gaweda, 1985). The interaction effect revealed that the total sugars increased more in fruits harvested at early stages, but less in fruits harvested at mid and late maturity stages of harvest. It may due to more initial starch content in fruit harvested at early mature stages as compared to fruits harvested at mid or late mature stages (Table 1) resulting in high total sugars in early harvested fruits. The increased total sugar may in part be due to the loss of moisture during storage (Veravrbeke *et al*., 2003), resulting in higher concentration of sugars per unit volume of water.

**Titratable Acidity (%):** There were significant differences in percent acidity of different apple cultivars. The maximum titratable acidity (0.56 %) recorded in cultivars Mondial Gala and Royal Gala, while minimum titratable acidity (0.50 %) observed in Red Delicious, followed by Golden Delicious with 0.51 % however, the difference was non significant. The percent acidity significantly declined with the increase in storage that decreased from 0.69 % observed in fresh harvested fruits to 0.37 % for fruits stored for 150 days. A significant variation in titratable acidity was observed in relation to harvesting stages. The maximum titratable acidity (0.59 %) recorded in the apple fruits at early harvesting stage. The minimum titratable acidity (0.49 %) measured at late harvesting stage followed by mid harvested fruits with 0.52 % however, the variation was non significant. The interaction of storage durations and harvesting stages also significantly affected titratable acidity. The maximum titratable acidity (0.79 %) recorded at early harvesting stage after 0 days storage while the minimum titratable acidity (0.35 %) observed at late harvesting stage after 150 days storage (Fig. 4). The titratable acidity of the fruit depends on the rate of metabolism especially respiration which consumed organic acid and thus decline acidity (Riveria, 2005). The fruit being living organs that respires even after harvested from the tree and during storage which consume the organic acids (Ghafir *et al*., 2009) and hence decrease the titratable acidity of the fruit (Ghafir *et al*., 2009).

**Ascorbic acid (mg/100g):** Ascorbic acid is an important quality characteristic of apple fruit, specially desired for its antioxidant properties (Lata, 2007). Though, the peel of apple fruit is richer source of Vitamin C than the flesh, yet it is correlated with the flesh Vitamin C content (Boyer and Liu, 2004). The maximum ascorbic acid content was recorded in cultivar Red Delicious (12.49 mg/100g) followed by Mondial Gala and Royal Gala with 11.53 and 11.43 mg/100g respectively. The least ascorbic acid was observed in cultivar Golden Delicious (10.27 mg/100g) (Table 2). The ascorbic acid decreased significantly from 14.18 to 8.68 mg/100g during 150 days storage at 5±1 $^0$C. Harvesting stages also significantly affected the ascorbic acid content of apple fruit. Ascorbic acid was the lowest in fruits harvested at early maturity stage (10.11 mg/100g), which increased to 11.68 and 12.50 mg/100g in fruits harvested at mid and over mature stages respectively. The interaction effect of cultivars and storage durations on ascorbic acid was also significant. The maximum ascorbic acid (14.76 mg/100g) recorded in cultivar Red Delicious after 0 day storage, while the minimum ascorbic acid (8.19 mg/100g) observed with 150 days storage in cultivar Royal Gala. The interaction of storage durations and harvesting stages also significantly affected ascorbic acid. The maximum ascorbic acid (15.23 mg/100g) recorded at late harvesting stage after 0 day storage while the minimum ascorbic acid (7.11 mg/100g) recorded at early harvesting stage after 150 days storage (Fig. 5). The cultivars Red Delicious had the maximum ascorbic acid followed by Mondial Gala and Royal Gala while the least ascorbic acid was observed in cultivar Golden Delicious. The apple cultivars differ significantly in their ascorbic acid content (Ali *et al*., 2004; Nour *et al*., 2010). But it generally average around 12.8 mg/100 g fruit (Lee *et al*., 2003) and generally decline during storage (Hayat *et al*., 2003). The ascorbic acid content of apple fruit may also depends on the stage at which the fruits are harvested. Generally, the fruit harvested at early maturity had lower ascorbic acid than later stages of harvest, indicating that the fruit may have still been synthesizing ascorbic acid when harvested at the early mature stages. Since the degradation of ascorbic acid is faster at higher than lower temperature (Pardio-Sedas *et al*., 1994), harvesting at late mature stage would have little ascorbic acid as compared to early harvested apples. Similarly, the early harvested apples tend to lose more ascorbic acid (45.81%) as compared to mid or late harvested fruit with 35.61 and 35.78% respectively. It is also interesting to note that while cultivars Royal Gala, Modial gala and Red Delicious had non significant differences in ascorbic acid content, the percent ascorbic acid loss of different cultivars revealed that Royal Gala lost 44.17% of its initial ascorbic acid as compared to only 30.69% in cultivar Red Delicious.

**Firmness (kg/cm$^2$):** Fruit firmness, that depends on total soluble solids (TSS) contents as well as the texture of apple fruit (Weibel *et al*., 2004; Peck *et al*., 2006). The fruit firmness was varied significantly among apple cultivars. The maximum firmness of 5.85 kg/cm$^2$ was noted in Red Delicious. The minimum firmness (5.08 kg/cm$^2$) was recorded for Royal Gala followed by Mondial Gala and Golden Delicious with 5.09 and 5.34 kg/cm$^2$ respectively, however, the effect was non significant among these cultivars. The firmness significantly decreased from 6.62 kg/cm$^2$ for fresh fruits to 4.09 kg/cm$^2$ for fruits stored for 150 days. Harvesting stages significantly affected the firmness of apple fruit. The maximum fruit firmness (5.88 kg/cm$^2$) was recorded at early harvested fruit, followed by fruits at mid harvesting stage with 5.33 kg/cm$^2$ and the least firmness (4.81 kg/cm$^2$) was observed at late harvesting stage (Table 2). It is important for edible quality, postharvest handling and market value of apples (Stow, 1995; De-Ell *et al*., 2001). Thus, the loss of fruit firmness during storage is a serious concern as it results in quality losses (Kov *et al*., 2005) leading to soft and mealy fruit and hence less consumers (Gomez, *et al*., 1998). The fruit firmness varied significantly with cultivars, with Red Delicious being the most firm cultivar while Royal Gala was the least. The difference in fruit firmness among apple cultivars indicate that apple cultivars may vary in their pectin composition and that causes rapid softening in Golden Delicious during storage (Billy *et al*., 2008). The fruit firmness was also significant at different stages of maturity with the maximum fruit firmness recorded in fruit harvested at early stages of maturity while the least was observed in fruit harvested at late harvesting stage. The firmness of the fruit depends on the texture of the flesh and changes in primary cell wall during ripening (Fuller, 2008). It may involve disassembly of primary cell wall and middle lamella structures (Jackman and Stanley, 1995) due to enzymatic activities (Yamaki and Matsuda, 1977) and pectin solubalization (Chang-Hai *et al*., 2006). Thus, the mechanical strength of cell walls is decreased with a concomitant decrease in the firmness of fruits (Kov *et al*., 2003; Kov *et al*., 2005).

**Table 1. Effect of harvesting stages and storage on weight lost. Juice content, TSS and total sugars of apple cultivars**

| Cultivar | Weight Loss (%) | Juice Content (%) | TSS (%) | Total Sugars (%) |
|---|---|---|---|---|
| Royal Gala | 2.43 b | 52.04 b | 11.26 | 10.83 |
| Mondial Gala | 2.35 b | 54.40 ab | 11.24 | 10.85 |
| Golden Delicious | 2.83 a | 52.43 b | 11.66 | 11.29 |
| Red Delicious | 2.42 b | 58.54 a | 11.79 | 11.31 |
| LSD at α 0.05 | 0.30 | 5.34 | NS | NS |
| **Storage (days)** | | | | |
| 0 | 0.00 | 61.28 | 10.02 | 9.67 |
| 150 | 5.02 | 47.43 | 12.95 | 12.47 |
| Significance level | * | * | * | * |
| **Harvesting Stages** | | | | |
| Early | 3.34 a | 47.68 b | 10.07 c | 9.31 c |
| Mid | 2.26 b | 56.05 a | 11.47 b | 10.89 b |
| Late | 1.93 b | 59.33 a | 12.92 a | 12.98 a |
| LSD at α 0.05 | 0.35 | 6.25 | 0.68 | 0.71 |
| **Interactions** | | | | |
| C × S | *Fig. 1 | ns | ns | ns |
| C × H | *Fig. 2 | ns | ns | ns |
| S × H | *Fig. 3 | ns | *Fig. 5 | *Fig. 6 |
| C × S × H | *Fig. 4 | ns | ns | ns |

Mean followed by similar letter(s) in column do not differ significantly from one another,
ns = Non Significant and * = Significant at 5 % level of probability.
C × S = Interaction of cultivar and storage duration
C × H = Interaction of cultivar and harvesting stage
S × H = Interaction of storage duration and harvesting stage
C × S × H = Interaction of cultivar, storage duration and harvesting stage

**Table 2. The effect of harvesting stages and storage on titratable acidity, ascorbic acid, firmness, bitter pit and soft rot of apple cultivars**

| Cultivar | Titratable Acidity (%) | Ascorbic Acid (mg/100g) | Firmness (kg/cm$^2$) | Bitter Pit (%) | Soft Rot (%) |
|---|---|---|---|---|---|
| Royal Gala | 0.56 a | 11.43 b | 5.08 b | 5.72 c | 10.53 c |
| Mondial Gala | 0.56 a | 11.53 b | 5.09 b | 5.77 c | 10.83 bc |
| Golden Delicious | 0.51 b | 10.27 c | 5.34 b | 11.23 b | 12.76 b |
| Red Delicious | 0.50 b | 12.49 a | 5.85 a | 14.22 a | 15.52 a |
| LSD at α 0.05 | 0.05 | 0.64 | 0.36 | 2.31 | 2.21 |
| **Storage (days)** | | | | | |
| 0 | 0.69 | 14.18 | 6.62 | 0.00 | 0.00 |
| 150 | 0.37 | 8.68 | 4.09 | 18.47 | 24.82 |
| Significance level | * | * | * | * | * |
| **Harvesting Stages** | | | | | |
| Early | 0.59 a | 10.11 c | 5.88 a | 11.69 a | 9.52 c |
| Mid | 0.52 b | 11.68 b | 5.33 b | 9.39 a | 12.49 b |
| Late | 0.49 b | 12.50 a | 4.81 c | 6.63 b | 15.22 a |
| LSD at α 0.05 | 0.05 | 0.75 | 0.42 | 2.71 | 2.59 |
| **Interactions** | | | | | |
| C × S | ns | *Fig. 8 | ns | ns | ns |
| C × H | ns | ns | ns | *Fig. 10 | *Fig. 12 |
| S × H | *Fig. 7 | *Fig. 9 | ns | *Fig. 11 | *Fig. 13 |
| C × S × H | ns | ns | ns | ns | ns |

Mean followed by similar letter(s) in column do not differ significantly from one another,
ns = Non Significant and * = Significant at 5 % level of probability.
C × S = Interaction of cultivar and storage duration
C × H = Interaction of cultivar and harvesting stage
S × H = Interaction of storage duration and harvesting stage
C × S × H = Interaction of cultivar, storage duration and harvesting stage.

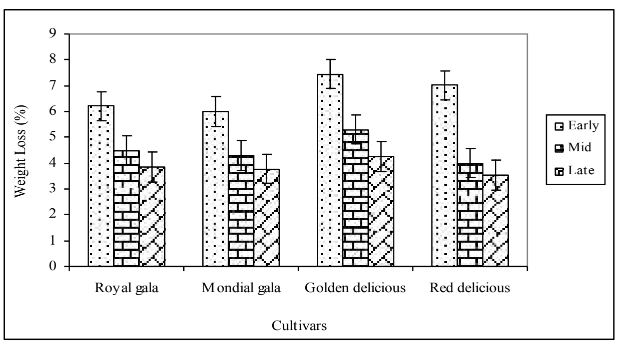


**Figure 1. Interactive influence of cultivars and harvesting stages on percent weight loss of apple fruits**

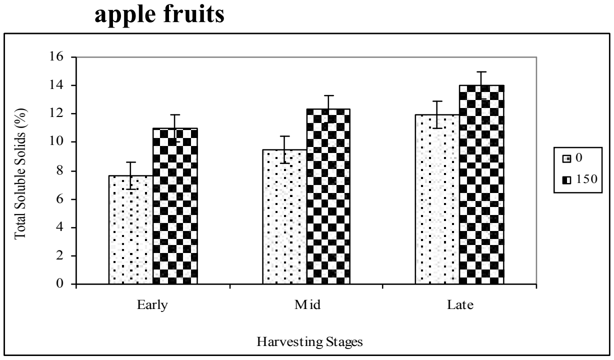


**Figure 2. Interactive influence of harvesting stages and storage on total soluble solids of apple**

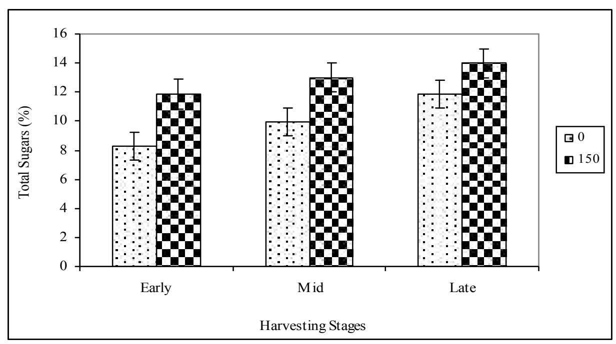


**Figure 3. Interactive influence of harvesting stages and storage on total sugar of apple fruits**

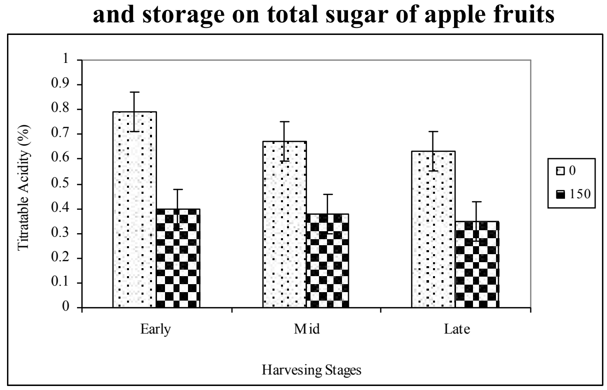


**Figure 4. Interactive influence of harvesting stages and storage on acidity (%) of apple fruits**

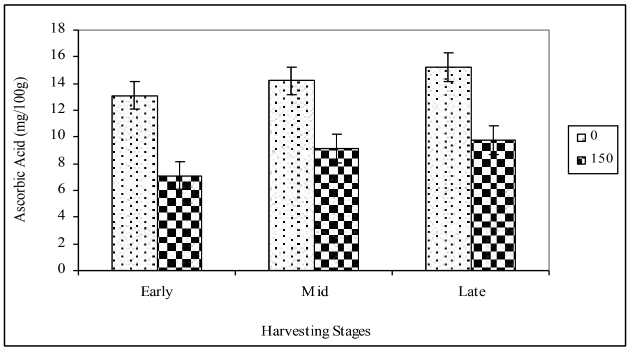


**Figure 5. Interactive influence of harvesting stages and storage on ascorbic acid (mg/100g) of apple fruits**

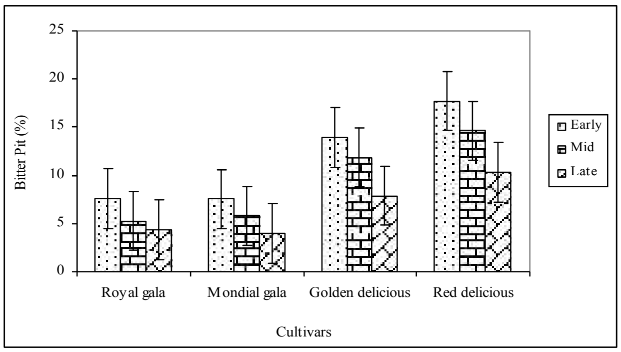


**Figure 6. Interactive influence of cultivars and harvesting stages on bitter pit (%) of apple**

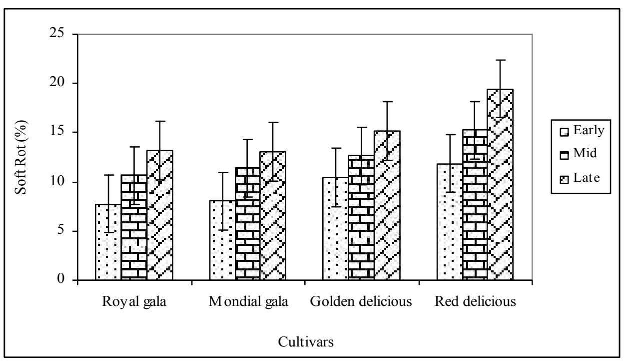


**Figure 7. Interactive influence of cultivars and harvesting stages on soft rot (%) of apple**

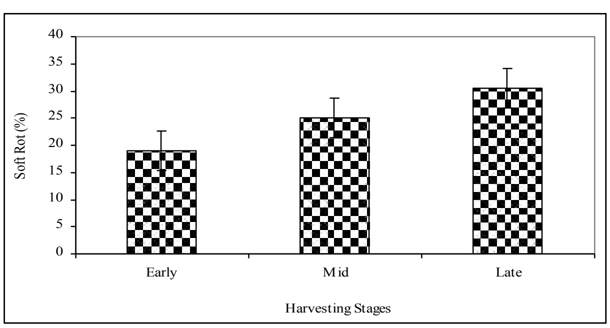


**Figure 8. Influence of harvesting stages on soft rot (%) of apple fruits stored for 150 days**

**Bitter pit (%):** The apple cultivars significantly varied in relation to bitter pit incidence. The maximum bitter pit incidence (14.22 %) observed in Red Delicious, followed by Golden Delicious with 11.23 %. The minimum bitter pit (5.72 %) recorded in Royal Gala, followed by Mondial Gala with 5.77 %, with the difference being non significant. Bitter bit incidence was significantly increased to 18.47 % with 150 days storage. Harvesting stages had significantly affected the bitter pit incidence. The maximum bitter pit incidence (11.69 %) observed in fruits at early harvesting stage, followed by mid and late harvesting stages with 9.39 and 6.63 % respectively (Table 2). The interaction of cultivars and harvesting stages significantly affected percent bitter pit. The maximum bitter pit incidence (17.70 %) observed in cultivar Red Delicious at early harvesting stage while the minimum bitter pit incidence (3.97 %) recorded in Mondial Gala at late harvesting stage (Fig. 6). The interaction of storage durations and harvesting stages also significantly affected the incidence of bitter pit. The maximum bitter pit incidence (23.38 %) recorded at early harvesting stage after 150 days storage. The sensitivity to bitter pit depends on genetic factors as well as growth conditions and maturity at harvest (Crouch, 2003; Pesis *et al*., 2009), thus it is likely to observe significant variations in different apple cultivars. It is observed that cultivars Red Delicious was more susceptible than Golden Delicious (Crouch, 2003) and while cultivar Royal Gala was the least sensitive to bitter pit incidence. Generally, the incidence of bitter pit significantly increases with increasing storage duration (Pesis *et al*., 2009) may be due to redistribution of calcium resulting in decreased calcium levels in the peel with increasing storage duration. Harvesting stages also significantly affected the bitter pit incidence so that it decreased by 43.28% in fruit harvested at late mature stage as compared fruit harvested at early mature stage. The apple fruits should be harvested at optimum maturity (Ingle *et al*., 2000) and both early and late harvest is not desirable (Meresz *et al*., 1993) with early harvested fruits being more sensitive to bitter pit (Juan *et al*., 1999). The interaction of cultivars and harvesting stages revealed that in all the cultivars under study, the bitter pit incidence percentage was the highest for early harvested fruit and declined with delaying harvesting to mid or late mature stages (Ferguson *et al*., 1993).

**Soft rot (%):** Significant differences among apple cultivars have been recorded for percent soft rot during storage. The soft rot was maximum (15.52 %) for Red Delicious, whereas, minimum percent soft rot (10.53 %) observed in cultivar Royal Gala, followed by Mondial Gala and Golden Delicious with 10.83 and 12.76 % respectively. The soft rot in apple fruit was significantly increased to 24.82 % during 150 days storage. Soft rot was significantly increased with delaying harvesting time. The maximum soft rot (15.22 %) observed at late harvesting stage, followed by mid and early harvesting stage with 12.49 and 9.52 % respectively (Table 2). The interaction of cultivars and harvesting stages significantly affected percent soft rot incidence. The maximum soft rot (19.45 %) observed in cultivar Red Delicious at late harvesting stage while minimum soft rot (7.75 %) recorded in Royal Gala at early harvesting stage (Fig. 7). The interaction of storage durations and harvesting stages also significantly affected percent soft rot. The maximum soft rot (30.43 %) recorded at late harvesting stage after 150 days storage (Fig. 8). The soft rot of apple fruit is due the development of brown and watery lesions on the skin of the apple that generally extend into the flesh (Watkins and Rosenberger, 2002). Significant differences among apple cultivars were observed among different cultivars with Red Delicious being the most sensitive (Watkins and Rosenberger, 2002.) than Royal Gala and Mondial Gala. Since apple cultivars are generally selected for resistance to certain postharvest diseases (Spotts *et al*., 1999), the incidence of different pathogens on apple fruit depend on cultivar (Spotts *et al*., 1999). The mean soft rot incidence significantly increased by 24.82 % during 150 days storage and the increase was more in fruits harvested at later stage of maturity than fruits harvested at mid or early maturity stages (Kader, 1985). The interaction of cultivars and harvesting stages significantly affected percent soft rot incidence with the maximum soft rot observed in cultivar Red Delicious at late harvesting stage while minimum soft rot was recorded in Royal Gala at early harvesting stage. The soft rot incidence was the minimum at early mature stage of harvest but increased with advance in maturity stages (Erkan and Pekmezcu, 2004). It is a common observation that the fruits which are more susceptible to different pathogens as they advance in ripening (Robertson *et al*., 1990) due to either senescence (Murray *et al*., 1998) or more susceptibility to mechanical injury (Kader, 2002).

**Conclusions:** Apple cultivar Red Delicious, despite good quality attributes, is also susceptible to bitter pit as well as soft rot incidence, thus measures like calcium treatment must be taken to ensure decrease in bitter pit and soft rot incidence. Cultivar Royal Gala has the lowest bitter pit incidence but all other quality attributes were relatively poor, so measures like high relative humidity during storage should be taken to improve its quality. Fruits harvested at mid harvesting stage with relatively low incidence of bitter pit and soft rot as well as good quality parameters as compared to early and mid harvested fruits are recommended for long term storage.

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