

Influence of maturity stages on postharvest physico-chemical properties of grapefruit (*Citrus paradisi* var. 'Shamber Tarnab') under different storage durations

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Abstract

The present study was conducted to evaluate the effect of maturity stages on the physicochemical characteristics of grapefruit (*Citrus paradisi* cv. 'Shamber Tarnab') under storage conditions for 60 days at ambient temperature (16 ± 1 °C with 55-60% relative humidity). Grapefruits were harvested at different maturity stages, namely mature green (MG) and full ripe (FR). The fruits of both stages were assessed for different physical quality parameters at 15 days interval. The experimental results showed that ascorbic acid content, titratable acidity, fruit firmness, percent disease incidence was higher at FR stage. In contrast, weight loss, percent juice content, total soluble solid (TSS), and TSS/acid ratio at MG (mature green) were lower than that of FR fruits. Regarding storage durations, the fruit firmness, titratable acidity, percent juice content, ascorbic acid content decreased significantly, whilst total soluble solid, TSS/Acid ratio, weight loss, and percent disease incidence increased significantly with the extension of storage duration from 0 to 60 days. As concerned to its interactive effects, the highest ascorbic acid content, titratable acidity, percent juice content, and maximum fruit firmness were observed in fresh grapefruit, harvested at (MG) mature green stages, whereas the maximum total soluble solid, percent disease incidence, and TSS/Acid ratio were recorded in fruit harvested at (FR) full ripe stage, stored for 60 days at room temperature. Similarly, the Pearson's Correlation Analysis ($p > 0.05$) of grapefruit was positive effect for most of the quality traits of grapefruit at different storage durations and maturity stages. It was concluded that grapefruit could be harvested at the mature green stage (MG) for sustaining quality attributes up to 60 days of storage at room temperature.

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Keywords: grapefruit; maturity; postharvest decay; 'Shamber'; shelf life

Introduction

Citrus paradisi is one of the most important fruit crops known by humans since antiquity. From South East Asia, citrus has become immensely popular worldwide and is now grown in the sub-tropical belt from latitude 40° North to 40° South in both humid and arid regions (Gorinstein *et al.*, 2001). Grapefruit (*Citrus paradisi* Macf.) is a prominent member of the Rutaceae family and was developed as an accidental cross between sweet orange and pomelo in Barbados. Grapefruit was introduced from Asia in the seventeenth century. It was named grapefruit because of growing in clusters like grapes (Yamamoto *et al.*, 1993). All the commercial varieties of grapefruit have been originated in Florida except 'Red Blush' (Ruby). Grapefruit cultivar 'Shamber' was originated in California and introduced in Pakistan in 1945 (Zeigler and Wolfe, 1961). Grapefruits are globally cultivated in all the citrus-producing areas of the world. China is the top producer of grapefruit (4930000 tons) followed by Vietnam (818914 tons), the United States of America (511650 tons), and Mexico (488776tons) (FAOSTAT, 2019). The total area of fruit crop is 6, 52,000 hectares and its production is 57,42,000 tons, out of which 28% are under citrus crop in Pakistan (Anonymous, 2006). Grapefruit is rich in essential nutrients and bioactive compounds like citric acid vitamin C, minerals, and flavonoids, therefore widely used fresh or processed into juice, marmalades, jams, jellies, wines (Josh, 2017). It also prevents constipation, asthma, and kidney stone and is helpful in decreasing the hazardous effect of obesity and diabetes. It acts as a skin cleanser, improves our immune system, and also helps in brain proper functioning (Josh, 2017).

Postharvest decay is mainly affected by harvest and handling, also postharvest decay reduces with proper handling and treatment of agricultural products. At different maturity stages, the best quality of grapefruit can be achieved. Any non-conformity in optimum maturity stages may cause a reduction in the qualitative and quantitative attributes of the commodity. Quality of fresh commodities as well as storage is significantly influenced by maturity. Non-climacteric fruit is harvested at horticultural maturity so that it has all the qualitative attributes (Siddique and Dhua, 2010). Quality attributes such as fruit color (Dariva *et al.*, 2021), total antioxidant capacity (El-Beltagi *et al.*, 2018), individual organic acid, and storage life (Suna *et al.*, 2019), are some of the prominent characteristics of citrus that are mostly influenced by harvesting maturity stages. Mukhim *et al.* (2015) reported that physiological and biochemical changes during fruit growth mostly affect the quality and shelf life of lemon fruit. Ladanya (2008) observed a gradual reduction in titratable acidity and ascorbic acid content and an increase in total soluble solid with the advancement of the maturation process in sweet orange.

The marketability of fruits and vegetables depends on the quality attributes such as physical appearance, firmness, and shelf life of commodities which are important from the consumer point of view (Abdallah *et al.*, 2021). At the time of purchasing, consumers judge the quality of commodities based on the appearance and firmness of fruits and vegetables (Rezk *et al.*, 2019; Dawi *et al.*, 2021; Zein *et al.*, 2021). Storage performance and quality of fruits depend on maturity stages. If grapefruit is harvested before optimum maturity its storage life is prolonged for a long period of time but its nutritional value and quality become reduced and vice versa (Kader, 1999; El-Beltagi *et al.*, 2020). Appropriate maturity stage for harvesting, harvesting methods, storage conditions, and proper treatments should be developed to prolong their shelf life (Ladaniya, 2001). Very few experimental studies were observed on the effect of maturity stages on the postharvest performance of grapefruit was observed in Pakistan. The objective of this experimental study was to investigate the influence of maturity stages and storage duration alone and in combination with the quality characteristics of grapefruit. This study will contribute to citrus farmers and food processors to estimate the possible fruit quality based on harvesting maturity stages and to identify the highest bioactive compounds i.e ascorbic acid, a prominent and helpful antioxidant compound for diabetics' patients.

Materials and Methods

Plant material

The grapefruit (*Citrus paradisi* var. 'Shamber Tarnab') were picked from a fully mature tree grafted on sour orange rootstock during 2016-17 from a commercial orchard namely Newly Development Research Farm, Horticulture Section located at The University of Agriculture Peshawar-Pakistan (S E). The grapefruits trees were planted 5 m wide between the rows and 5 m within the rows in the North-South direction and all the trees received uniform cultural practices including nutrition, irrigation, and plant protection. The fruit harvested at different maturity stages were selected on basis of maturity stages namely; mature green (MG) and full ripe stage (FR). All the selected fruits were of uniform size and free from blemishes and other defects. The grapefruits of both maturity stages were shifted to the Post-harvest Research laboratory Department of Horticulture Peshawar within a short time and stored at room temperature (16 ± 1 °C and relative humidity 55-60%) for 60 days. The experiment was laid out in Complete Randomized Design (CRD) with two factors i.e. maturity stages (mature green (MG) and full ripe stage (FR)) and storage duration (0, 15, 30, 45, 60 days). Each treatment was repeated three times during the experiment.

Following quality attributes during the respective storage duration were studied in the experiment

Weight loss (%)

Weight loss of randomly selected five fruits in each treatment was determined in every storage period and was expressed in percentage. The weight loss was estimated by using the following formula.

Where X= Weight of fresh fruit (g)

Y= Weight after storage interval (g)

$$\text{Weight loss (\%)} = \frac{X - Y}{X} \times 100$$

Fruit firmness (kg.cm⁻²)

Fruit firmness was measured with help of a Penetrometer. The probe of the penetrometer was inserted at the ends of the fruits for measuring fruit firmness and readings of each treatment were taken in kg.cm⁻² (Pocharski *et al.*, 2000).

Total soluble solid (°Brix)

Total soluble solids in fruit juice were determined through a hand refractometer as described (A.O.A.C. 1990).

Percent disease incidence

Percent disease incidence per treatment was calculated after 15 days of interval by using the following formula.

$$\text{Percent disease incidence} = \frac{\text{No. of diseased fruits}}{\text{Total No. of fruits}} \times 100$$

Fruit juice content (%)

The weight of the fruit was measured through electronic balance. After removal of the fruit peel, the juice was extracted with the manual juicer and then the weight of the juice was determined through digital balance. The percent juice content was evaluated by the given formula (Rehman *et al.*, 1982).

$$\text{Percent juice content} = \frac{\text{average weight of juice (g)}}{\text{average fruit weight (g)}} \times 100$$

Titrateable acidity (%)

Titrateable acidity was determined by using neutralization reaction as described by Association of Official Analytical Chemists (A.O.A.C., 1990). Ten ml grapefruit juice was taken in 100 ml volumetric flask and made the volume of 100 ml by adding distilled water up to the upper mark of the flask to make 10% solution. Then from 10% solution, 10 ml of these diluted samples were taken into the separate beaker and as an indicator, 2-3 drops of phenolphthalein were added and then titrated against 0.1 N NaOH solutions until the light pink color appeared.

$$\text{Titrateable Acidity(\%)} = \frac{N \times T \times F \times 100}{D \times S} \times 100$$

N=NaOH Normality

T= in (ml) NaOH used.

F=constant acid factor 0.0064(citric acid)

D=In ml Citrus Sample taken for dilution

S=Diluted sample taken for titration in ml

Ascorbic acid content (mg.100g⁻¹)

Dye method was used for the determination of ascorbic acid as described (Rangana, 1976). With help of a pipette, 10 ml of juice were taken from the extracted fruit and was added to the graduated cylinder. With the help of oxalic acid solution, the volume was raised to 100 ml to make 10% solution. 10% solution was titrated from the burette containing dye (50 mg of 2-6 dichloro-phenol indophenol + 42 mg baking soda) until the pink color was attained. Each sample reading was noted. By using the following formula, Vitamin C content was calculated.

$$\text{Ascorbic acid content (mg/100g)} = \frac{F \times T \times 100}{D \times S} \times 100$$

F = dye factor

T = ml of dye used for sample titration

D = ml of sample taken for dilution

S = ml of diluted juice taken for titration

Statistical analysis

The Statistical package Statistix (8.1) was used to test the experimental data in two-way (maturity stages and storage duration) analysis of variance (ANOVA). The least Significance differences (LSD) test was used to test the mean comparison at 5% level of significance among various treatments. Pearson's correlation was conducted by MV App (Julkowska *et al.*, 2019).

Results*Weight loss (%)*

Weight loss of grapefruit was significantly influenced by maturity stages, storage duration and their interaction (Table 1). The interaction of maturity stages and storage duration revealed that the highest weight loss was recorded in fruit harvested at FR stage that was stored for 60 days followed by FR stage grapefruit stored for 45 days. While the fruit harvested at MG and stored for 15 days attained lowest value of weight loss.

Fruits firmness (kg.cm⁻²)

The influence of maturity stages, storage duration and their interaction on fruit firmness were prominently significant ($P \leq 0.05$) (Table 1). Overall, the fruits firmness was highest in fruit harvested at MG stage as compared to FR stage which later on showed a decline in fruit firmness with prolonging storage duration of 60 days. The highest fruit firmness was recorded in freshly harvested fruit at MG stage followed by

MG stage fruit, stored for 15 days. While the lower value of fruit firmness was observed in FR stage grapefruit at 60 days of storage.

Total soluble solid ($^{\circ}$ Brix)

Total soluble solids content is an important aspect of fruit's quality of which 75-80% is sucrose. The maturity stages, storage duration, and their interaction showed significant difference for total soluble solid (Table 1). The highest value of total soluble solid was recorded in grapefruit harvested at FR stage that was stored for 60 days followed by grapefruit harvested at FR stage at 45 days of storage. While freshly harvested grapefruits, at MG stage attained lowest value of total soluble solid.

Table 1. Mean values and analysis of variance (ANOVA) of results of the evaluation of grapefruits regarding weight loss, fruit firmness, total soluble solid and percent disease incidence at different maturity stages and storage durations

Maturity stages (M)	Weight loss (%)	Fruits firmness (kg.cm ⁻²)	Total soluble solids Solid ($^{\circ}$ Brix)	Percent disease incidence
Mature green (MG)	18.26±6.99 ^b	3.03±0.62 ^a	7.51±0.48 ^b	19.38±6.15 ^a
Full ripe (FR)	21.67±6.21 ^a	2.87±0.69 ^b	7.86±0.73 ^a	25.82±8.96 ^b
Storage duration (S)				
0	0.00	3.53±0.04 ^a	6.87±0.14 ^c	0.00
15	12.34±1.99 ^d	3.47±0.07 ^b	7.19±0.13 ^d	12.70±1.67 ^d
30	14.99±1.96 ^c	3.39±0.08 ^c	7.75±0.29 ^c	20.19±3.20 ^c
45	23.89±2.15 ^b	2.31±0.19 ^d	8.08±0.14 ^b	23.95±2.18 ^b
60	28.65±0.72 ^a	2.05±0.01 ^c	8.53±0.42 ^a	33.57±5.81 ^a

Results show the mean values \pm standard error. Means followed different letters were significant at $P \leq 0.05$ from each other.

Percent disease incidence

Grapefruits were checked thoroughly for disease incidence in both stages of maturity at every storage duration. Effect of maturity duration, storage duration and their interaction on percent disease incidence of grapefruit was found significant (Table 1). The highest percent disease incidence was noted in grapefruits harvested at FR stage that was stored for 60 days as compared to grapefruits harvested at MG stage, stored for 15 days which attained lowest value of percent disease incidence.

Fruit juice content (%)

A significant difference ($P \leq 0.05$) existed in the juice content between maturity stages, storage duration, and their interaction (Figure 1). The results showed a steady decline in percent juice content of grapefruit at MG and FR stage fruit during storage duration of 60 days. However, fruits harvested at FR stage showed higher decrease in percent juice content with prolonging storage duration as compared to grapefruit harvested at MG stage.

Titrateable acidity (%)

The maturity stages, storage duration, and their interaction significantly influenced the titrateable acidity of grapefruit (Figure 2). The interactive effect of maturity stages and storage duration revealed that maximum titrateable acidity was recorded in freshly harvested grapefruit at MG stage, whereas grapefruit harvested at FR stage, stored for 60 days had minimum titrateable acidity. The highest decline in titrateable acidity (1.34 to 0.46%) was observed in grapefruit harvested at FR stage when the storage duration was increased to 60 days as compared to MG harvested grapefruit for the same duration.

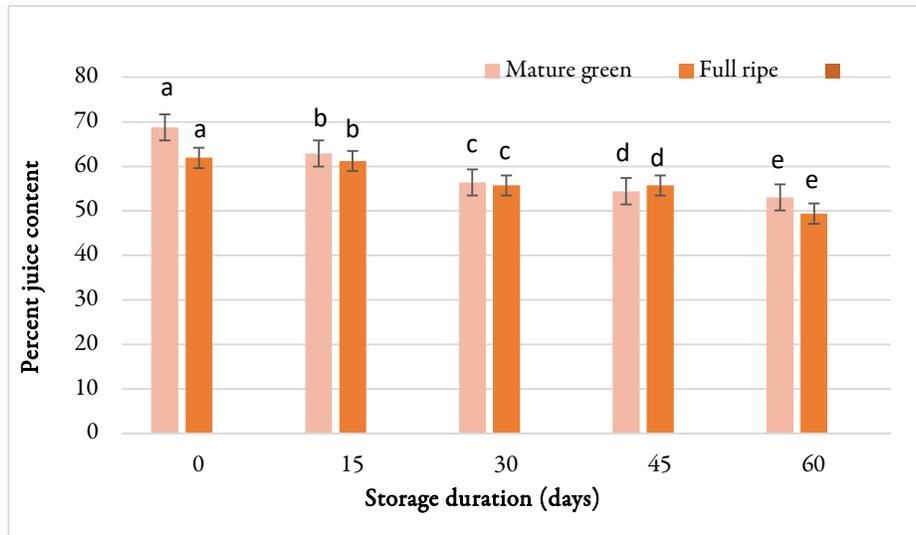


Figure 1. Fruits juice content of grapefruit as influenced by interaction of maturity stages and storage duration

In each column, data are provided as means \pm SD, and means with various letters are significantly different ($p < 0.05$) for each concentration.

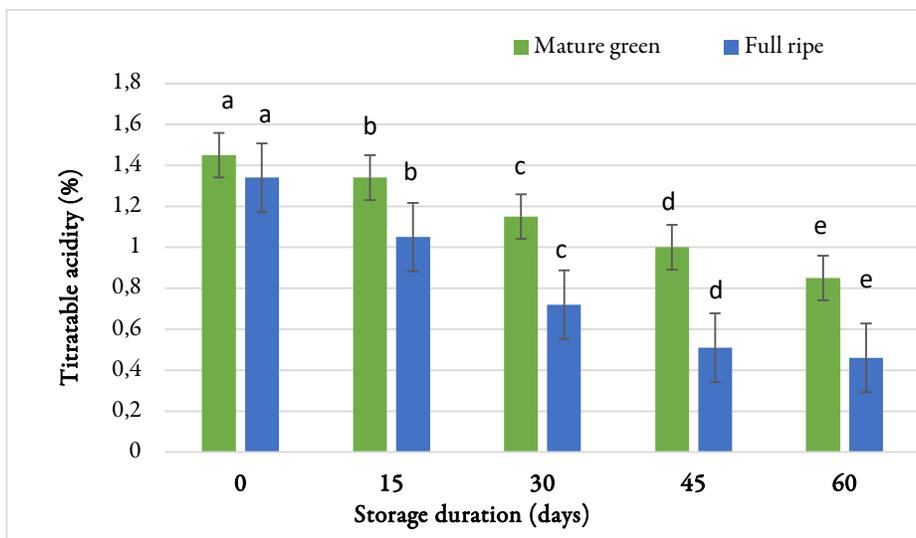


Figure 2. Titratable acidity % of grapefruit as influenced by interaction of maturity stages and storage duration

In each column, data are provided as means \pm SD, and means with various letters are significantly different ($p < 0.05$) for each concentration.

TSS/Acid ratio

TSS/acid ratio of grapefruit was significantly influenced by maturity stages, storage duration and their interaction. The results (Figure 3) revealed a significant increase in TSS/Acid ratio of grapefruit at MG and FR stage at prolonging storage duration of 60 days. Whereas FR stage harvested fruit showed a prominent increase in TSS/Acid ratio (5.23 to 19.45) as compared to MG stage grapefruit (4.64 to 9.54) when the storage duration was increased to 60 days.

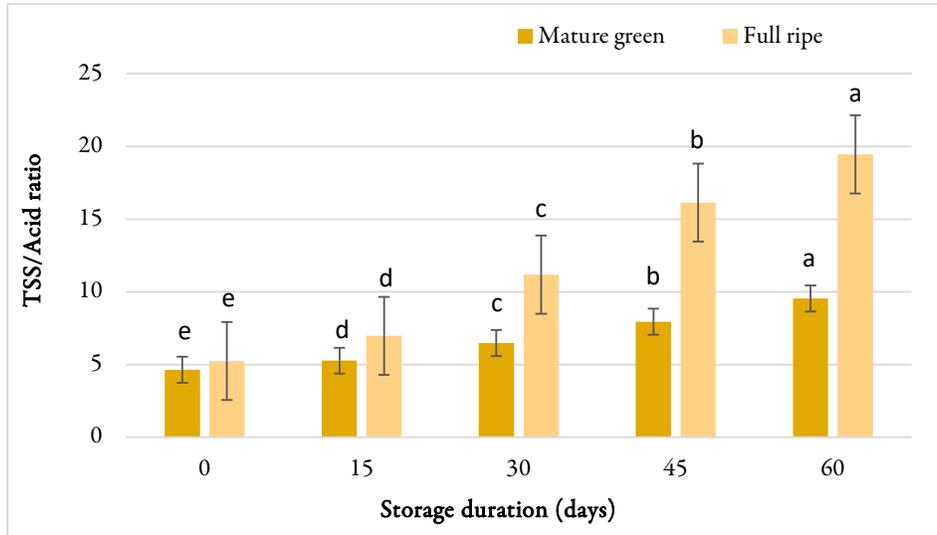


Figure 3. TSS/Acid ratio of grapefruit as influenced by interaction of maturity stages and storage duration. In each column, data are provided as means \pm SD, and means with various letters are significantly different ($p < 0.05$) for each concentration.

Ascorbic acid (mg.100g⁻¹)

The data pertaining to ascorbic acid content was significantly influenced by maturity stages, storage duration, and their interaction (Figure 4). The interaction between maturity stages and storage duration indicated that optimum ascorbic acid was noted in fresh grapefruits that were harvested at MG stage. While the grapefruits harvested at FR stage, and stored for 60 days recorded minimum ascorbic acid. The ascorbic acid content of MG stage harvested fruits decreased from 52.36 to 38.02 mg.100g⁻¹ as compared to grapefruits harvested at FR stage which attained lowest decrease in ascorbic acid content during storage duration of 60 days.

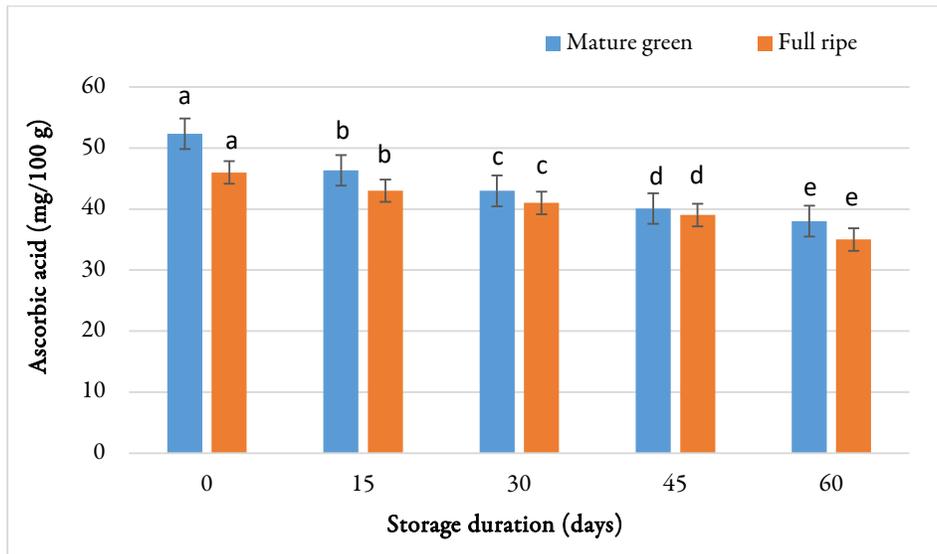


Figure 4. Ascorbic acid content of grapefruit as influenced by interaction of maturity stages and storage duration. In each column, data are provided as means \pm SD, and means with various letters are significantly different ($p < 0.05$) for each concentration.

Pearson's Correlation Analysis

Pearson's Correlation Analysis ($P > 0.05$) was performed for the quality attributes of grapefruits at different storage durations. A positive correlation was noticed between quality attributes of grapefruits except for fruit juice content and fruit juice pH that observed a negative correlation with each other (Figure 5).

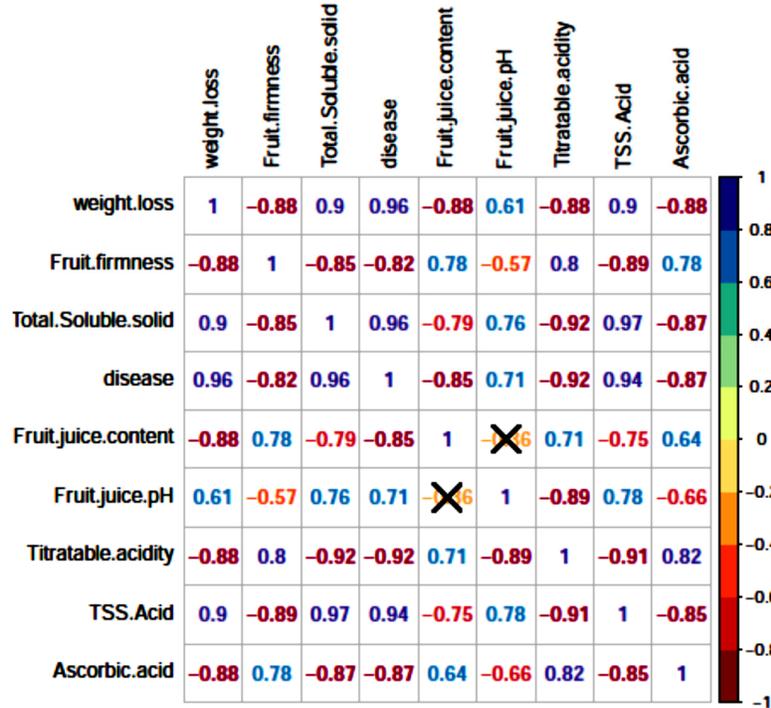


Figure 5. The figure shows the Pearson correlation coefficients between selected traits. The color and size of the circle reflect the strength of the correlation. The correlation coefficients are calculated using raw data, with a total number of 30 samples. X represents the non-significant association between different quality attributes of grapefruit.

Discussion

In the current investigation, the percent weight loss was significantly influenced by maturity stages and storage duration. The weight loss in stored fruits exhibited significantly a decrease trend from green mature to full ripe stage (Table 1). The variation in the weight loss at different maturity stages and different storage periods might be due to differences in respiration rates. The current results are in conformity with the finding of a previous study (Eaks, 1970) who reported that with the advancement in development and ripening, the rate of respiration exhibited a decreasing trend from green mature to full ripen stage. Grapefruit loses moisture from different segments through transpiration and respiration that adversely affects the fruit's weight and appearance by causing wilting, shriveling, and fruit softening during storage. The water loss from the citrus fruits is closely related to many physiological and rind disorders (Palou *et al.*, 2015). The increase in weight loss during storage might be due to loss of moisture which reduced fruits turgidity and enhanced fruits softening and also due to starch conversion into soluble solids (Antoniali *et al.*, 2007). Weight loss from the fruits or vegetables is correlated with the shelf life of produce. The decrease in weight of the fruits might be due to the environmental factors of the storage house (relative humidity of the environment) under which the fruits were kept as a result fruits become wrinkle and less firm and had less consumer preference (Alhassan *et al.*, 2014).

Citrus is non-climacteric fruit and had a maximum shelf life as compared to climacteric fruits. The composition of ethylene and respiration of non-climacteric fruits are different from climacteric fruits during ripening and maturity. The results are also supported with the findings of Attia (1995) who stated that the produced weight loss decreased with the passage of time. Similarly, the current study results are in accordance with the findings of Rab *et al.* (2010) who reported that fruits weight loss significantly increased with increasing storage duration of sweet orange.

The mean fruits firmness was significantly influenced by maturity stages and storage duration (Table 1). The difference in fruits firmness at both stages is supported by Sinha *et al.* (1962) who reported that the advancement of fruits maturation or ripening Valencia oranges attributed to a significant decrease in fruits firmness. The firmness of the fruit depends on the texture of the flesh and changes in the primary cell wall during ripening (Fuller, 2008). It may involve disassembly of the primary cell wall and middle lamella structures (Jackman and Stanley, 1995) due to enzymatic activities (Yamaki and Matsuda, 1977) and pectin solubilization (Chang-Hai *et al.*, 2006). Thus, the mechanical strength of cell walls decreased with a significant decrease in the firmness of fruits (Kov and Felf, 2003). Rapid catabolic processes in orange fruits enhance the rate of respiration. The firmness of fruits decreases with more activity of pectic enzyme especially pectin-methylesterase and poly-galacturonase which loosen cell wall and decrease the cell integrity (Salunkhe and Desai, 1984). Fruit firmness decrease with increasing maturity stages. The present results are supported by the findings of Zhou (2011) who noticed a decrease in fruits firmness with increasing maturity stages. Similarly, fruits firmness decreases during a prolonged storage period as confirmed previously (Lahay *et al.*, 2013) who noticed a decrease in fruits firmness of sweet orange during an increasing storage period. Fruit firmness loss during storage is a critical concern since it leads to quality losses, resulting in soft and mealy fruit that is less acceptable to consumers (Kov *et al.*, 2005).

The total soluble solid content in the juice of grapefruits exhibited an increasing trend from the mature to the green stage of fruits harvested with the extension of storage duration (Table 1). There was a significant increase in TSS of the grapefruit harvested at MG and FR stage which are supported by previous studies that as fruits mature, the TSS content increases at an increasing rate during the early stages of ripening and increases at a decreasing rate as the fruits progress towards the full ripe stage (Samson, 1986). The flavor and marketability of most fruits depend upon total soluble solids that showed the concentration of sugar and number of soluble components in the flesh which becomes degraded with prolonged storage duration (Singh *et al.*, 2014; Shokr *et al.*, 2021). The increment in total soluble solids of fruits with the extension of storage duration might be due to the high rate of respiration and metabolic activity which enhanced the breakdown of protopectin to pectic substance, disaccharides to monosaccharides, and sucrose to fructose and glucose (Sharma *et al.*, 2012). The present finding is in accordance with the finding of Ali *et al.* (2011) who reported that the higher respiration rate increases the synthesis and use of metabolites result in higher TSS due to the more conversion of carbohydrates to sugars. The degradation of pectin, hemicelluloses, and cellulose in cell wall within the segment release some soluble constituent which has a direct effect on total soluble solids (Echeverria and Ismail, 1990). High total soluble solid contents and lower acidity at optimum maturity also support the findings of Rizzolo and Eccher (2006) who reported that total soluble solid content increased and moisture content decreased up to the maximum maturity of grapefruits. Similarly, the results showed that the total soluble solids of grapefruits increase with increasing storage duration. Our results are in line with the finding of Rab *et al.* (2012) who noticed that total soluble solids increased with increasing storage duration of sweet orange.

Citrus fruits are highly perishable and susceptible to illness. The results indicated that highest disease incidence at FR stage during storage might be due to the accumulation of moisture around the fruits that provides favorable environments for microbial growth and thus aggravates spoilage (Jawandha *et al.*, 2012). The higher spoilage with fruit harvested at FR stage might be due to the more enzymatic activities and disintegration of the cell wall (Navjot and Sukhjot, 2010). Fungal diseases are mostly noticed in high amounts in sweet orange and different fungicide treatments are used for their control that is hazardous for human health.

So, for control of different fungal diseases, another way should be used that is human friendly. Disease incidence of fruits increased with increasing storage duration (Schirra *et al.*, 2000; Al-Khateeb *et al.*, 2019; Al-Khateeb *et al.*, 2019). A previous study stated that 50 percent of sweet orange fruits become diseased when the environmental condition for the pathogen was favorable (Abdel-El-Aziz and Mansoor, 2006). The increment in percent disease incidence during the storage period could be due to high respiration rate, more skin permeability for water loss, fruits senescence, enzymatic degradation of the fruits cell wall, and high susceptibility to decay (Ciccarese *et al.*, 2013; Ghazzawy *et al.*, 2021).

Citrus paradisi fruits quality depends on many factors; juice content is one of the most important characters of citrus fruits. The quality of fruits juice plays an economical role in the citrus industry. The citrus fruit juice is based on sugar content that is the most important economic factor for the processing industry, 95% of citrus crops are further processed in making different drinks (Mouei and Choumane, 2014). In orange fruits during maturation elongation of juice sacs occur that accumulate more juice in sacs cell until its full maturation (Spiegel-Roy and Goldschmidt, 1996). Juice content in cell vacuole is rich in organic acids and other soluble constituents like salts and amino acid, however, besides this hesperidin, naringin crystals, and calcium oxalate were also found in the juice sacs and rind of citrus fruits (Baldwin, 1993). The results indicated that increasing storage duration decreases juice content of fruits because respiration rate increase during storage as a result transpiration of solutes occurs and thus juice contents of fruit decreases (Khan and Ahmad, 2005). During ripening many changes occur in fruits quality like reduction in fruits firmness and titratable acidity, increase in total soluble solids, and development of fruits color. The present results are in line with the finding of Serrano *et al.* (2006) who reported that prolonging storage duration minimizes the *Citrus paradisi* percent fruit juice content. Similarly, the percent juice content of apple fruits depends mainly on the water content and its loss from the fruits. Thus, cultivars distinguished by more weight loss are generally less juicy (Dzonova *et al.*, 1970).

The titratable acidity in FR stage fruits is generally lower than that of MG stage fruit during prolonging storage duration might be attributed to increase in sugar substances in the fruits as a result of which flavor of the fruit improved. The difference in titratable acidity at both maturity stages (MG and FR stage) might be attributed to the decreasing trend of citric acid, malic acid, and fumaric acid as maturation advances from green stage to yellow stage of lemon (Suna *et al.*, 2019). Similarly, a decrease in titratable acidity was observed during maturation with the utilization of individual organic acids in pyruvate decarboxylation reaction (Rhodos *et al.*, 1968). Generally, *Citrus paradisi* juice contains a significant amount of organic acids like oxalic, tartaric, malic, lactic, citric, and ascorbic acid but citric acid is considered the most abundant acid of the total acid constituent of juice followed by malic acid. During storage reduction in acid contents of juice occur due to the use of acid as the source of energy which converts organic acid to form sugar (Karadeniz, 2004). Sugar and acids are related to fruits taste, fruits flavor that should be maintained by having a proper amount of titratable acidity. During storage rate of respiration increases which consume organic acid and reduce the fruits acidity that affects the fruits flavor (Ali *et al.*, 2011). The results reported that grapefruits pertain low value of titratable acidity by increasing storage duration and by delaying the harvesting of grapefruits to retain more titratable acidity. Similar findings were observed by Ghafir *et al.* (2009) who reported that a decline in the acidity of apple cultivars occurs due to the use of organic acid for the production of organic compounds during ripening.

The higher change in TSS/Acid ratio at FR and MG stage grapefruit during storage might be attributed due to hydrolytic changes in the starch concentration to sugar (Beaudry *et al.*, 1989) and decline in organic acids due to respiration-related consumption (Riveria, 2005) which consequently fruit palatability. Results of the current research are in line with the findings of Hussein *et al.* (2008) in apple. The sweetness of the fruits is not related to sugar but also related to acidity (Castellari *et al.*, 2001). Fruits having a low index of (TSS/TA) also having a sour taste, while those having a high index value are unpleasant. During extending storage duration and increase in TSS/Acid ratio might be due to an increase in TSS and a corresponding decrease in acidity with maturity. Similar findings were also observed by Dhillon and Cheema (1991) in peach 'Flordasan'.

Ascorbic acid content is a vital constituent of citrus fruits (Gupta *et al.*, 2000) for both taste and nutritional value (Khan and Dangles, 2014). Since vitamin C is rapidly lost during extended storage of citrus fruits (Coloumb *et al.*, 1984), its retention is of prime importance in postharvest handling of citrus fruits. The ascorbic content is high in green fruits and with passage of time, the amount of ascorbic acid goes to decline in fruits (Combes, 2001; El-Beltagi *et al.*, 2019a, b). The decline in ascorbic acid might be due to high pH and temperature (Emese and Nagymat, 2008). Similarly, Cepeda *et al.* (1993) reported that with maturation and prolonging storage duration the ascorbic acid content of grapefruits decreases. During storage decline in vitamin C occur above 0 °C temperatures (Ajibola *et al.*, 2009). The loss of ascorbic acid content might be due to the loss of antioxidants activity during post-harvest storage (Davey *et al.*, 2000). Increased storage time reduced ascorbic acid levels in fruits. The current findings are in line with the finding of Rab *et al.* (2010) who stated that ascorbic acid of sweet orange decreased with extending storage duration. These findings are in close agreement with the findings of a previous study (Obeed and Harhash, 2006) who reported that in Mexican lime the value of ascorbic content significantly decreased with increasing the storage duration. Ascorbic acid gradually declines with increasing storage duration because it is a relatively less stable compound (Ansari and Feridoon, 2007). The ascorbic acid content in fruits shows its nutritional value. During extending storage duration of fruits the ascorbic acid reduces due to its volatile nature that evaporates from fruits surface during respiration (Ripasarda *et al.*, 2001; Abd El- Rahman and Mohamed, 2014; Helmi and Mohamed, 2016). In plants, especially in citrus ascorbic acid content plays a key role not only as a free radical scavenger but also as an electron donor for ascorbate peroxidase in the reduction of H₂O₂ to H₂O (Jimenez *et al.*, 2002; Mohamed *et al.*, 2016; Farag *et al.*, 2020; El-Beltagi *et al.*, 2022).

Conclusions

It was concluded that the mature green (MG) stage of grapefruits was more effective by retaining fruits firmness, percent juice content, titratable acidity, ascorbic acid with a minimum weight loss and percent disease incidence up to 60 days of storage and is recommended for the consumption of diabetic patients. Similarly, grapefruits harvested at the full ripen (FR) stage sustained its quality attributes up to 45 days at room temperature (16±1 °C and relative humidity of 55-60%) while a gradual decline was noted in the quality attributes with extending the storage durations is recommended for normal consumption based on consumer preferences.

Authors' Contributions

Conceptualization, HSE, IU, MS, AB and WFS; methodology, STS, SMA, AU, IA and FA; software, HSE, IU, MS, AB and WFS; validation, STS, SMA, AU, IA and FA; formal analysis, HSE, IU, MS, AB and WFS; investigation, HSE, AB, STS, SMA, AU, IA and FA; resources, HSE, IU, MS, AB and WFS; data curation, STS, SMA, AU, IA and FA; writing-original draft preparation, STS, SMA, AU, IA and FA; writing-review and editing, HSE, AB, STS, SMA, AU, IA and FA; visualization, STS, SMA, AU, IA and FA; supervision, HSE, IU, MS and AB; project administration, HSE, IU, MS and AB; funding acquisition, HSE, IU, MS and AB. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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