Research Article

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Impact of Maturity Stage on Postharvest Quality of Strawberries Cold Stored for Fresh Consumption

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ABSTRACT
Strawberries, being a non-climacteric fruit, is usually harvested near maturity for optimal flavour and quality. However, this could also lead to a limited shelf life being highly perishable. However, the ripening stages could be a possible solution to minimizing the losses of post-harvest. Therefore, current study was performed to evaluate influences of ripening stages effecting the quality of strawberry fruit. Strawberry fruit was picked at four ripening stages unripe, semi-ripe, fully ripe and over-ripe maturity stages and stored at 5°C and were evaluated every alternate day for changes in fruit quality. The results concluded that red ripe fruits retained maximum fresh fruit weight and only 10%of fruit was un-marketable after 10 days of storage period. On the contrary, the highest decay rate was observed in over-ripe fruits and 50% of the fruit was unmarketable after 10 days of storage. Moreover, red ripe fruits were organoleptically more acceptable and retained higher total soluble solids whereas unripe and semi-ripe achieved low organoleptic scores due to higher total titratable acids. High levels of sugar in over-ripe fruits favored a high incidence of pathogen attack. From this experiment we can suggest that if fruits are picked at red ripe stage will have optimal quality, moisture level, TSS, pH, TSS/acid ratio, TA, and good organoleptic score. Therefore, strawberry fruits for fresh eating should be picked at red ripe maturity stage.
Keywords: *Fragaria x ananassa*, postharvest, maturity stage, fruit quality, Pakistan.

INTRODUCTION

The strawberry fruit (*Fragaria x ananassa*) is non climacteric fruit. So, it is preferred to harvest near the full ripened stage in order to get finest eatable quality fruit. The judgement of picking is always crucial because, at different ripening stages, the quality of strawberry fruit changes and postharvest shelf life may also be influenced. The higher TSS contents in strawberry fruit were observed in red ripe strawberry stage whereas vitamin C, total ellagic acid and higher total phenolics was recorded at pink maturity stage (1, 33). The ascorbic acid is vital for continuing regular growth as well as development in human body and is abundantly present in strawberry. Strawberry fruit is also a decent source of different metabolites such as anthocyanins, furanone, ester aldehydes, sulphur compounds and other trace elements. These metabolites are accumulated during strawberry fruit ripening which gives it a unique taste and flavor (3, 31). The highest content of ascorbic acid was recorded at the unripe stage which dropped with development in the maturity (1). This drop in the ascorbic acid

Article History
Received: October 20, 2023, Accepted: December 15, 2023, Published: December 31, 2023

content showed that the ascorbic acid is quite an unstable vitamin which decreases as the maturity advances.

Though, non-climacteric in nature but strawberry which was harvested on early color stage of development still has the capacity to change color without altering sugars and acid contents during storage (4, 28). So, the fruit is harvested at the red ripe stage to increase its shelf life and to maintain its better quality for fresh consumption. Harvesting at the proper stage promotes strawberry good quality and processing for further consumption. Strawberry fruit is picked at numerous color stages of development i.e. initial color changing stage, half red colored, three-quarters and full red color stage which influence its storability and quality (5, 24, 35). The general ripeness index considered for the optimal picking stage of strawberries based on color is red which results from anthocyanin production in strawberries (6, 32, 34). When fruit of strawberry is picked at the third quarter development color stage, its value, look, color, firmness along with acidity as well as TSS with lowest fruit decay is better as compared to the full ripened strawberry stage (7, 26).

Temperature plays an important role in the storage of all fruits so maintaining temperature throughout storage is most important factor which decreases the decay of the fruit and prolong the strawberry shelf life. In Pakistan, majority of the farmers and sellers store their fruit at ambient conditions due to absence of cold storage facilities. Ambient storage makes post-harvest managing very challenging as at the higher temperature the respiration rate also increases (8,36).

In Pakistan, the strawberry cultivar Chandler is the dominantly being grown in all strawberry production areas. Mostly the strawberry farmers are not aware regarding proper harvest time and stage of this delicate fruit. Mixed lots of fruits at varying maturity stages cause high postharvest losses and short market life of strawberries. The relationship of maturity stage with fruit quality and storability has not yet been reported in strawberry cv. Chandler is grown under the subtropical conditions of Pakistan. So, this study was initiated to investigate the best harvest stage which may lead to better consumer acceptability and extended storage life.

MATERIALS AND METHODS

The purpose of study was to explore the relationship between maturity stage of strawberry fruit with storability and fruit quality for fresh consumption. Strawberry fruits cv. Chandler was harvested at unripe (¼ pinkish red color), semi ripe (½ red color), fully ripe (¾ red color) and over-ripe (completely fresh red color) stages. Strawberries were picked in 500 gram PVC plastic boxes and brought to the lab within 45 minutes. Strawberries were kept at 5°C and 85% humidity for 12 days maximum. On alternate days, three boxes (one box per replication) from each category were randomly removed from storage and kept under ambient conditions for 60 minutes before physical and biochemical analyses.

Fresh fruit weight of all healthy fruits (without any sign of fungal infection or decay) was recorded with digital weighing balance and fruit weight average was computed by dividing weight of a fruit by total fruits per box. Changes in external fruit color were recorded using a five-point score chart. Ripe, undamaged, regular-shaped strawberries without any visible sign of fungal mycelia were classified as marketable and presented in percentages concerning several fruits in every category. Visual score of the strawberry fruits for fungal deterioration was evaluated according to five-point scale given by Babalar et al. (2007) (9, 30). Electric conductivity was determined by immersing 10 disks (5-mm diameter) of fruit tissues (ten fruits per replication) in 50 ml double distilled water at 25°C for 60 minutes. After recording the initial reading, disks were boiled to achieve maximum electrolyte leakage. The initial reading was divided into the final reading and multiplied by 100 to achieve a percentage of relative electrolyte leakage (10). For fruit dry weight, fruit slices were dried in a hot air drier at 65˚C until full dry weight was attained. The dry fruit percentage weight was obtained by dividing fresh fruit weight by dry fruit weight and multiplying by 100.

For biochemical analyses, fruit pieces of ten strawberry fruits were centrifuged on 10,000 rpm for 15 minutes. The liquid extract portion was isolated and subjected to the determination of biochemical parameters. The pH was obtained by using digital pH meter and TSS (%) were obtained by using digital refractometer (RS-5000, Atago, Japan). Total titratable acidity stated as a citric acid was obtained by titration with 0.1 mol L-1 NaOH to the titration end-point at a pH of 8.1 (11). Ascorbic acid content was obtained with 2,6-dichlorophenolindophenol titration as earlier described by Rahman et al. (2016) using a standard curve of different concentrations of ascorbic acid (96% p.a., Sigma Aldrich, Germany) and stated as (mg 100 g-1 of vitamin by fresh weight (12,25). Reducing, non-reducing and total sugars were determined as earlier described by (13). In order to conduct sensory analysis, fruits of the strawberry were divided in four pieces on clean plates which were unmarked. Samples of the fruits were positioned in randomized order for organoleptic assessment by a board of people consisting 15 persons. Each sample was assessed for texture, aroma, exterior look and flavor with a nine-point scale and sweetness, tartness/sourness with a five-point scale as described earlier (14, 15, 16,27,29).

Visual, instrumental and sensory data were statistically analyzed by analysis of variance (ANOVA) technique employing XLSTAT software (Addinsoft, Paris, France). Treatment means were further analyzed by the Fisher's least significant difference test at α=0.05.

RESULTS AND DISCUSSION

Relationship of field-grown maturity stages of strawberry fruit to marketability, fruit quality and consumer acceptability was explored in this study.

The collected data on fresh fruit weight shows that strawberry fruit diverse significantly according with maturity period or stage at harvest. The maximum fresh fruit weight (g) was observed in over-ripe (T4) strawberry fruits during the initial days but increased along with the storage period. The minimum fruit fresh weight (g) was observed in unripe (T1) followed by semi-ripe (T2) strawberry fruits. This was because of their small size and were not properly ripe. In case of full ripe (T4) strawberry fruits, fresh fruit weight was well maintained as compared to the other ripe stages of strawberries. So, overall the fresh fruit weight of strawberries improved with the development in its color during the storage.

The maximum fruit dry weight (15.9%) was observed in unripe (T1) strawberry fruit on 10th day of storage. The minimum fruit weight (5.7%) was observed in over-ripe (T4) strawberry fruits on the first day of storage. Overall, the dry weight of all fruit categories increased as storage duration advanced.

A maximum number of marketable fruits (%) in all treatments was observed up to 8th day of storage but on 10th day there was a sudden decrease in marketable fruits in all treatments. At the 12th day of storage, the marketable fruits (%) in all treatments were completely diminished. So, overall, we can say that the strawberry fruits at (5°C) can be stored for a maximum 10 days.

Maximum marketable fruit weight (19.4 g) was observed in over-ripe (T4) strawberry fruit on 4th day of storage. The minimum fruit weight (6.8g) was observed in unripe (T1) strawberry fruit on 12th day of storage. Overall, all the treatments showed an increase in fruit weight but the ripe (T3) strawberry fruit showed good marketable fruit weight throughout the storage period.

Maximum peel color (4.7) was observed in unripe (T1) strawberry fruits at the 4th day of storage. While lowest peel color (1.2) was observed in over-ripe (T4) strawberry fruits. The peel color was increased parallel in all treatments from green to red or red to dark red color.

The data regarding disease, decay, and damage incidence showed that over-ripe fruits decayed faster than the matured stages of strawberries. Higher total soluble solids in over-ripe strawberry fruits favored high disease and spoilage incidence. The lowest disease effect was recorded in semi-ripe (T2) strawberries at 2nd day of storage and in ripe (T3) strawberries at 4th day of storage (1.0). The highest disease incidence was recorded in over-ripe (T4) strawberries at 12th day of storage (6.0). As compared to the others the fully ripe (T3) strawberries showed less disease incidence on strawberry fruit. The higher disease incidence in ripe and over-ripe fruits was because of more delicacy and loss of cell integrity as result of more electrolyte leakage and fungal attack.

Decay incidence gradually increased from 6th day of storage and was maximum at 12th day.

From 1st day to 8th day, damage incidence was less but there was a gradual increase in damage incidence from 10th to 12th day of storage. Damage incidence was observed greater in ripe (T3) and over-ripe (T4) as compared to the unripe (T1) and semi-ripe (T2) strawberries due to their large size and their soft texture and increase in their ion leakage. The damage incidence was observed mainly due to the compression of fruits According to Nunes et al., (2002), fully ripe fruits had higher decay symptoms than at three quarter riped fruits (7).

The maximum ion leakage (53.4%) was observed in over-ripe (T4) strawberry fruit at 4th day. The minimum ion leakage (16.0%) was observed in unripe (T1) strawberry fruit at 6th day. Overall, the maximum ion leakage throughout the whole storage period was observed in over-ripe (T4) strawberry fruits followed by ripe (T3), semi-ripe (T2) and unripe (T1) strawberry fruits.

The maximum fruit TSS (9.7) was observed in over-ripe (T4) strawberry fruits at 12th day, whereas the minimum fruit TSS (6.6) was observed in semi-ripe (T2) strawberry fruits at 6th day. Overall study shows that the fruit TSS was increased during storage but there was a gradual upsurge in fruit TSS in all treatments from 8th day to 12th day during the storage. Nunes et al. (2002) found considerably higher TSS in full red than three quarter colored strawberries (7). The rise in TSS detected in the current study is in covenant with the report of Abdullah et al. (1985) (17, 18).

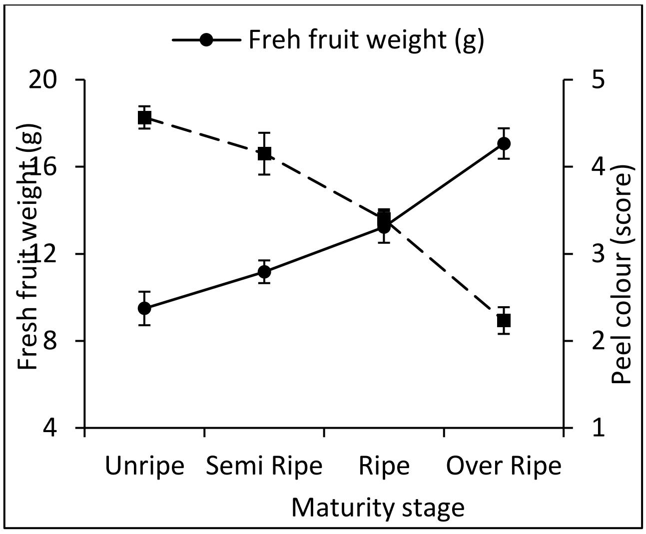
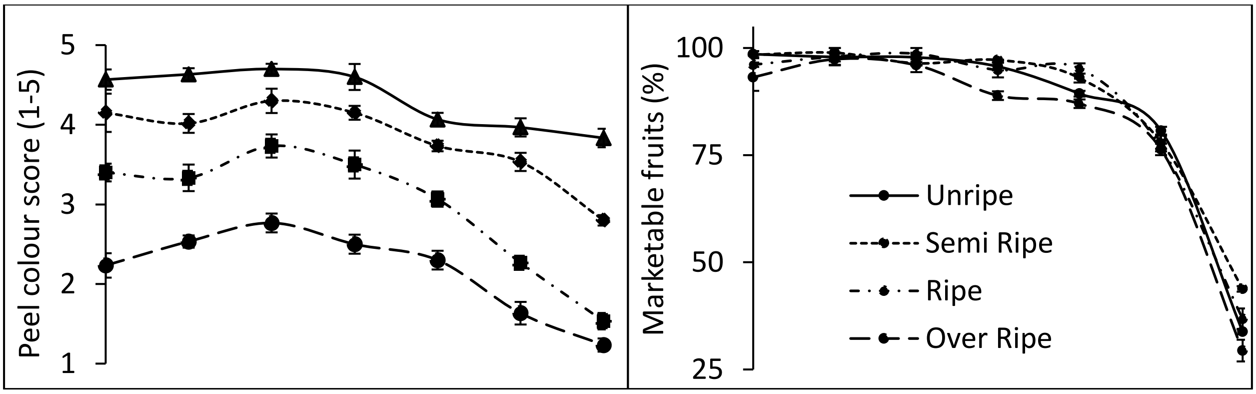


Figure 1: Changes in fresh weight and color of strawberry fruits with the progression of maturity stage. The fruit surface showing yellow or light pink color not red color was considered unripe, the fruit showing 25% red surface color was considered as semi-ripe, the fruit showing up to 75% red surface color was considered as ripe fruit, and the fruit showing more than 80% dark red surface color was taken as over-ripe fruit. Straight up bars direct average ± standard error (n≥30 fruits per replication, 3 replicates).



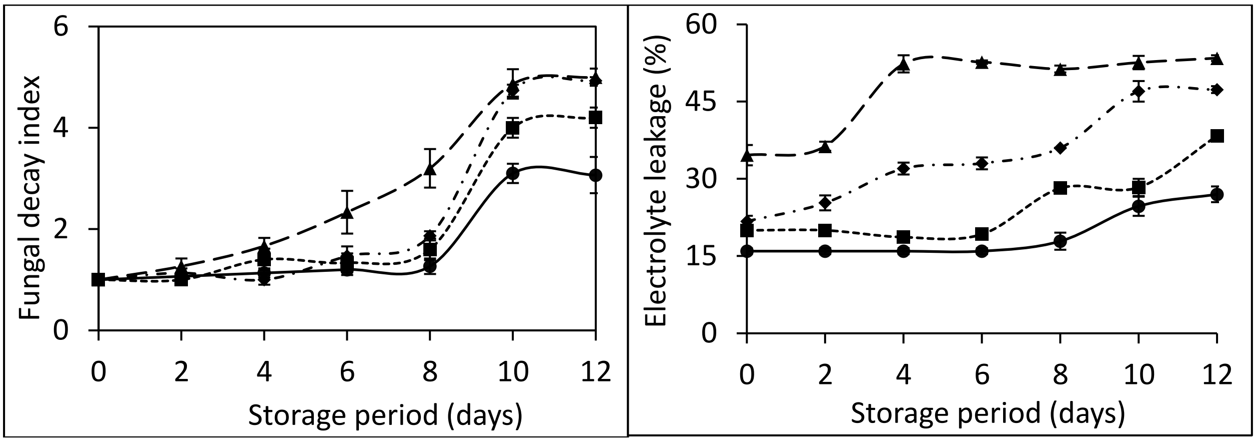


Figure 2: Maturity stage effect on development of fruit color (green to red), marketable period, disease incidence and ion leakage in strawberry stored at 5°C. Straight up bars indicate average ± standard error (n≥30 fruits per replication, 3 replicates).

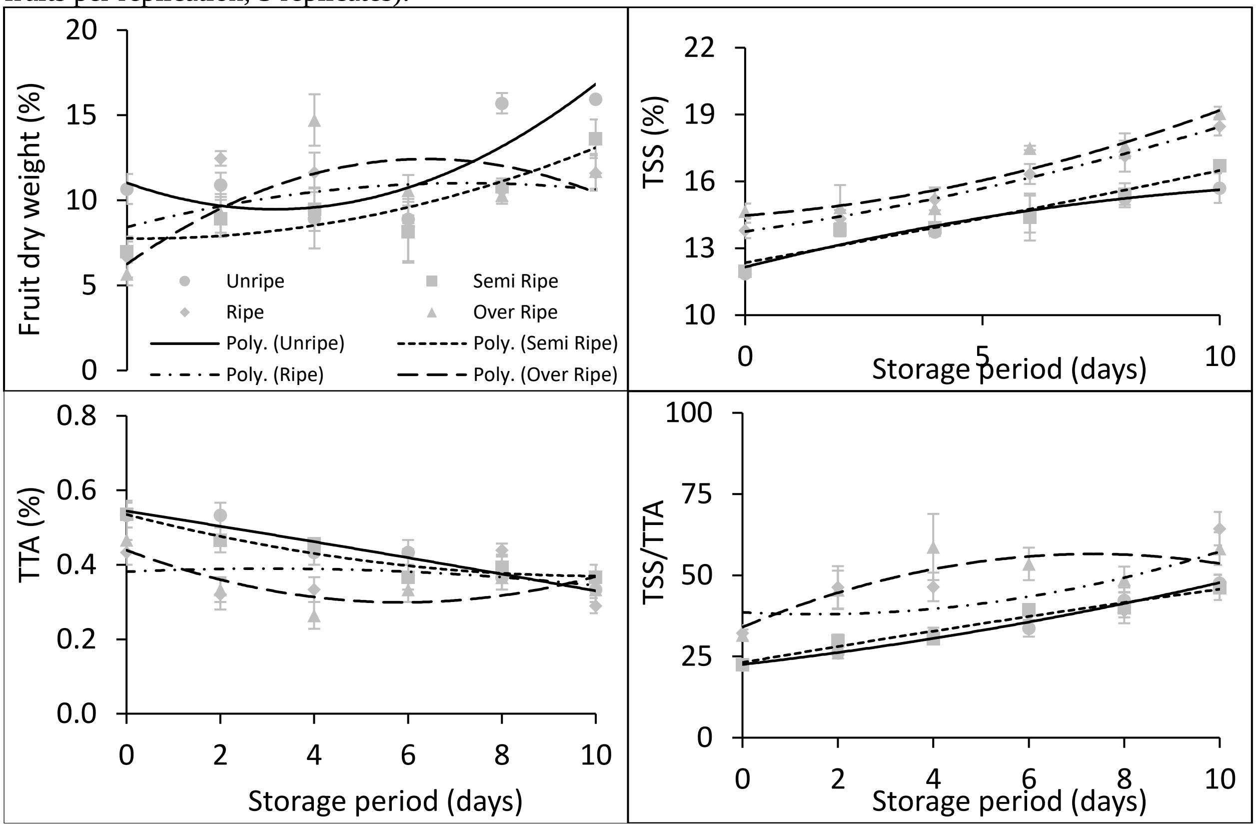
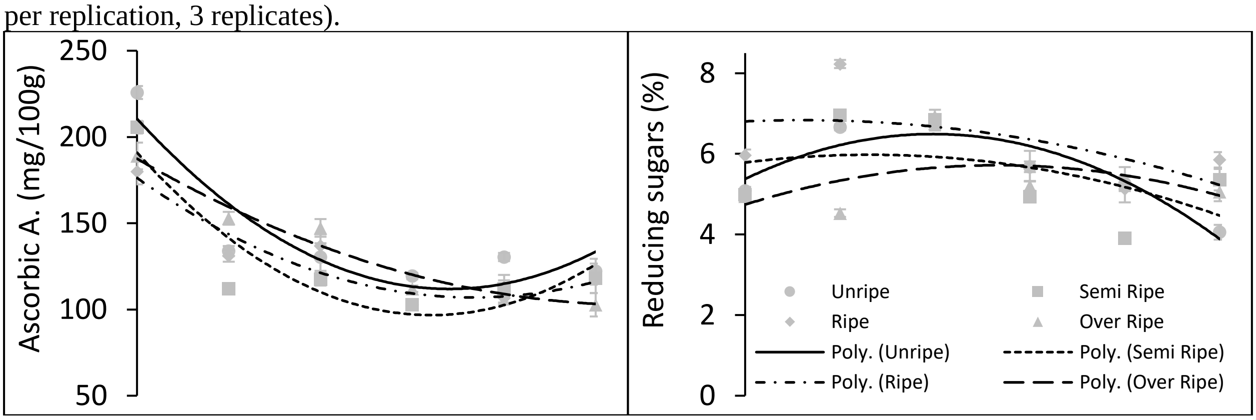


Figure 3: Effect of maturity stage on fruit dry weight, total soluble solids (TSS), total titratable acidity (TTA) and TSS/TTA ratio of strawberry stored at 5°C. Straight up bars indicate average ± standard error (n≥30 fruits per replication, 3 replicates).



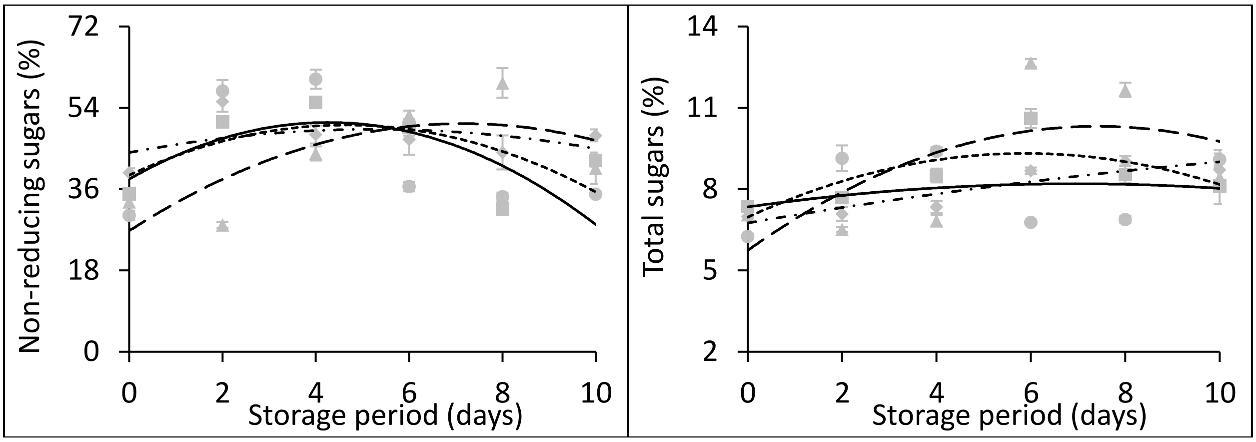


Figure 4: Effect of maturity stages on ascorbic acid contents, reducing sugars, non-reducing and total sugars in strawberry stored at 5°C. Vertical bars indicate average ± standard error (n≥30 fruits per replication, 3 replicates).

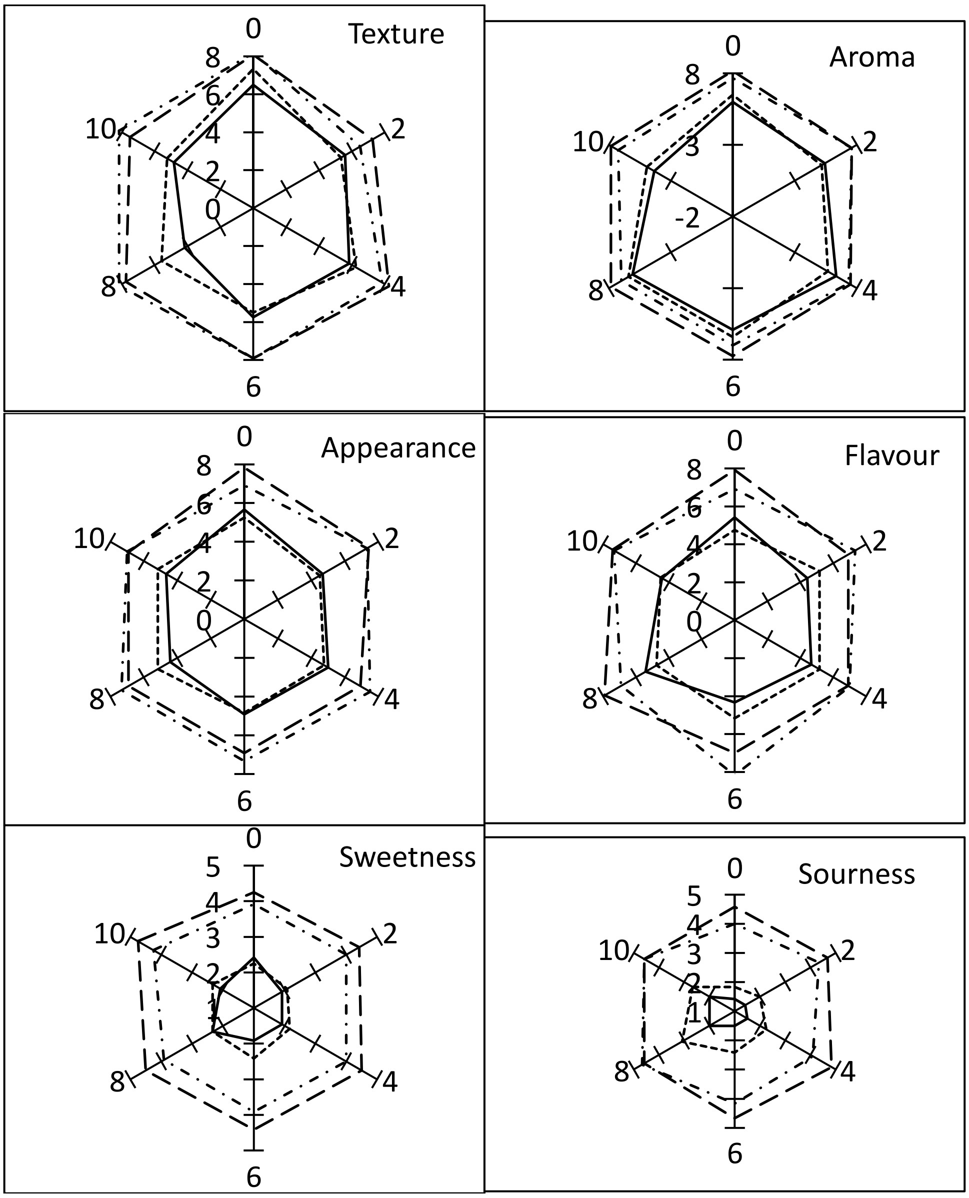


Figure 5: Effect of maturity stages on sensory attributes of strawberry stored at 5°C. Clock-wise axis values characterise storage period (0, 2, 4, 6, 8 and 10 days). Values on vertical axis characterise average organoleptic score allocated to fruit slice on a given day at specific maturity stage. Fruit slices from each maturity stage (triplicated) was evaluated by fifteen panellists.

The maximum value of pH (3.5) was observed in ripe (T3) strawberry fruits on 10th day of storage. The minimum value of pH (2.8) was observed in unripe (T1) strawberry fruits. Overall, during the storage period, the pH value was higher in ripe (T3) and over-ripe (T4) strawberry fruits. Organic acids are consumed during respiration therefore acidity decreases as the storage time increases while soluble sugars increase with the storage period resulting in increased pH in strawberry fruit. Nunes et al. (2002) reported that ripe strawberries have high pH then unripe strawberries (7). Similar was reported by Kader, (1991) that thin cell wall of the strawberry fruit causes fruit softening and maximum levels of vulnerability to fruit physical injuries (19). Our results also matched with the results of Akhtar et al., (2015) (20).

The maximum TTA (0.5%) was observed in unripe (T1) strawberry fruits at 1st day of storage. The minimum value of TTA (0.2%) was observed in over-ripe (T4) strawberry fruits at 12th day. The TTA (%) during storage decreases with respect to time but the ripe strawberry maintained its TTA (%) more as compared to the other maturity stages. The obtained results are similar to Montero et al. (1996), who revealed that strawberry fruit cv. Chandler at the fully red stage or during the senescing process had lower TA than unripe strawberry fruit (21).

The maximum value of TSS: TA (80.3) was observed in over-ripe (T4) strawberry fruits at 12th day. The upsurge in TSS/TTA was because the increase in TSS contents of fruits. Our obtained result were equivalent to the result obtained by Akhtar et al. (2015) (20).

The maximum ion leakage (53.4%) throughout the whole storage period was observed in over-ripe (T4) strawberries followed by ripe (T3), semi-ripe (T2) and unripe (T1) strawberry fruits (16.0%).

The highest value of ascorbic acid (225.8mg/100g) was observed in unripe (T1) strawberry fruits at 1st day of storage and the lowest value of ascorbic acid content (102.8mg/100g) was observed in over-ripe (T4) strawberry fruits at 10th day of storage. Ascorbic acid is a relatively unbalanced vitamin and usually declines from the unripe stage of development to semi-ripe, fully ripe and further to the over-ripe maturity stage in strawberry fruit. Spayd et al., (1981) also concluded the similar results (22).

The highest value (8.2%) was observed in ripe (T3) strawberry fruits at 2nd day of storage and the lowest value (3.9%) was observed in semi-ripe (T2) strawberry fruits at 8th day of storage.

The highest value of non-reducing sugars (60.3%) was observed in unripe (T1) strawberry fruit on 4th day. The minimum value of non-reducing sugars (28.1%) was observed in over-ripe (T4) strawberry fruits at 4th day of storage.

The maximum total sugars (12.7%) were observed in over-ripe strawberry fruits at 6th day of storage which was somewhat decreased at 8th day and 10th day. The sugar contents in strawberries were increased upon increased in maturity stage but up to some extent. The increase in total sugar was less in unripe and semi-ripe strawberries. However, the ripe strawberry maintained its total sugars well as compared to other strawberries. Our results were in accordance to the study performed by Rahman et al. (2016) which shows that concentration of total sugars are increased with the increase in storage period of strawberry (12). Similarly, Watson et al., (2002) also exhibited similar results (23).

Unripe and semi-ripe fruits generally achieved low score of organoleptic due to their high acid contents whereas ripe and over-ripe strawberry fruits achieved high score due to their high total soluble solid contents. The highest value of texture aroma and sweetness was observed in over-ripe (T4) strawberry fruit at 1st day of storage. The minimum value of texture, aroma, appearance, flavour and sweetness was observed in unripe (T1) strawberry fruits at 8th day of storage. The highest value of appearance and flavor was observed in ripe (T3) strawberry fruit at 10th day of storage. In unripe and semi-ripe strawberry fruits, the flavor was slightly increased throughout the storage period due to increase in TSS content of the fruit. The sweetness was slightly increased in unripe and semi-ripe strawberry fruit with the advancement of ripening. The lowest position score of tartness (4.8) was observed in over-ripe (T4) strawberry fruit at 4th day. The maximum position score of tartness (1.4) was observed in unripe (T1) strawberry fruits at 1st and 2nd day of storage.

CONCLUSION

Strawberries harvested at full-ripe stage had optimum individual fruit weight(g), dry fruit weight (%), unmarketable fruits (%), marketable fruits (%), fruit shape index, skin color score, disease, decay and damage incidence (score), total soluble solids (TSS, %), pH, titratable acidity (%), ascorbic acid (mg/100 g), and total sugars.

It’s accomplished at some point that fruit of strawberry harvested at the fully ripe stage (75% red color) was better for alot of the quality characteristics, hence strawberry should be harvested at the full ripe stage for fresh use.

REFERENCES

1. Pineli, L.d.L.d.O., Moretti C.L., dos Santos M.S., Campos A.B., Brasileiro A.V., Córdova A.C., & Chiarello M.D. (2011). Antioxidants and other chemical and physical characteristics of two strawberry cultivars at different ripeness stages. *Journal of Food Composition and Analysis*, 24,11-16. https://doi.org/10.1016/j.jfca.2010.05.004
2. Lee, S.K., & Kader A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, 20, 207-220. https://doi.org/10.1016/S0925-5214(00)00133-2
3. Zhang, J., Wang X., Yu O., Tang J., Gu X., Wan X., & Fang C. (2011). Metabolic profiling of strawberry (Fragaria ×ananassa Duch.) during fruit development and maturation. *Journal of Experimental Botany*, 62, 1103-1118. https://doi.org/10.1093/jxb/erq343
4. Kalt, W., Forney C.F., Martin A., & Prior R.L. (1999). Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. *Journal of Agricultural and Food Chemistry*, 47, 4638-4644. https://doi.org/10.1021/jf990266t
5. Maynard, D.N., & Sherman M. (1988). Strawberry production guide for Florida. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.
6. Manning, K. (1998). Isolation of a set of ripening-related genes from strawberry: their identification and possible relationship to fruit quality traits. *Planta*, 205, 622-631. https://doi.org/10.1007/s004250050365
7. Nunes, M.C.N., Morais A.M.M.B., Brecht J.K., & Sargent S.A. (2002). Fruit maturity and storage temperature influence response of strawberries to controlled atmospheres. *Journal of the American Society for Horticultural Science*, 127, 836-842.
8. Asrey, R., Jain R., & Singh R. (2004). Effect of pre-harvest chemical treatments on shelf-life of chandler strawberry (*Fragaria* x *ananassa*). *Indian Journal of Agricultural Sciences*,
9. Babalar, M., Asghari M., Talaei A., & Khosroshahi A. (2007). Effect of pre- and postharvest salicylic on ethylene production, fungal decay acid treatment and overall quality of Selva strawberry fruit. *Food Chemistry*, 105, 449-453. https://doi.org/10.1016/j.foodchem.2007.03.021
10. Huan, C., Jiang L., An X., Yu M., Xu Y., Ma R., & Yu Z. (2016). Potential role of reactive oxygen species and antioxidant genes in the regulation of peach fruit development and ripening. *Plant Physiology and Biochemistry*, 104, 294-303. https://doi.org/10.1016/j.plaphy.2016.05.013
11. Keutgen, A.J. & Pawelzik E. (2008). Influence of pre-harvest ozone exposure on quality of strawberry fruit under simulated retail conditions. *Postharvest Biology and Technology*, 49, 10-18. https://doi.org/10.1016/j.postharvbio.2007.12.003
12. Rahman, M.M., Moniruzzaman M., Ahmad M.R., Sarker B.C., & Khurshid Alam M. (2016). Maturity stages affect the postharvest quality and shelf-life of fruits of strawberry genotypes growing in subtropical regions. *Journal of the Saudi Society of Agricultural Sciences*, 15, 28-37. https://doi.org/10.1016/j.jssas.2014.05.002
13. Hortwitz, W. (1960). Official and tentative methods of analysis. Association of the Official Agriculture Chemist, Washington DC, 9, 320-341.
14. Jouquand, C., Chandler C., Plotto A., & Goodner K. (2008). A sensory and chemical analysis of fresh strawberries over harvest dates and seasons reveals factors that affect eating quality. *Journal of the American Society for Horticultural Science*, 133, 859-867. https://doi.org/10.21273/JASHS.133.6.859
15. Resende, J.T.V.d., Camargo L.K., Argandoña E.J., Marchese A., & Camargo C.K. (2008). Sensory analysis and chemical characterization of strawberry fruits. *Horticultura Brasileria*, 26, 371-374.
16. Schwieterman, M.L., Colquhoun T.A., Jaworski E.A., Bartoshuk L.M., Gilbert J.L., Tieman D.M., Odabasi A.Z., Moskowitz H.R., Folta K.M., Klee H.J., Sims C.A., Whitaker V.M., & Clark D.G. (2014). Strawberry Flavor: Diverse Chemical Compositions, a Seasonal Influence, and Effects on Sensory Perception. *PloS One*, 9, 88446. https://doi.org/10.1371/journal.pone.0088446
17. Abdullah, H., Rohaya M., & Zaipun, M. (1985). Physico-chemical changes during maturation and after ripening of bananas (*Musa Sapintum* CV. Embun). Journal of Tropical Agriculture and Food Science, 13, 341-347.
18. Tripathi, V., Ram, H., Jain, S., & Singh, S. (1981). Changes in developing banana fruit. Progressive Horticulture, 13, 45-53.
19. Kader, A.A. 1991. Quality and its maintenance in relation to the postharvest physiology of strawberry, p. 145-152, In: A. Dale and J.J. Luby (editors). The Strawberry into the 21st. Timber Press, Portland, Oregon

20. Akhtar, I., & Rab A. (2015). Effect of fruit ripening stages on strawberry (*Fragaria* x *ananassa* Duch) fruit quality for fresh consumption. *Journal of Agricultural Research*, 53.

21. Montero, T.M., Mollá E.M., Esteban R.M., & López-Andréu F.J. (1996). Quality attributes of strawberry during ripening. *Scientia Horticulturae*, 65, 239-250. https://doi.org/10.1016/0304-4238(96)00892-8

22. Spayd, S., & Morris J. (1981). Physical and chemical characteristics of puree from once-over harvested strawberries. *Journal American Society for Horticultural Science*, 106(1), 101-105.

23. Watson, R., Wright C.J., McBurney T., Taylor A.J., & Linforth R.S. (2002). Influence of harvest date and light integral on the development of strawberry flavour compounds. *Journal of Experimental Botany*, 53, 2121-9. https://doi.org/10.1093/jxb/erf088