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Original Research

Harvest Maturity Influences Fruit Quality of Carambola (*Averrhoa carambola* L.)

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ABSTRACT

Harvest maturity determines the shelf life and nutritional quality of fruits. The present study was planned to determine the effect of harvest maturity on fruit quality of carambola. Fruits of carambola (*Averrhoa carambola* L.) cv. "Arkin" were harvested at five maturity stages, i.e., M_1 (100% green), M_2 (75% green and 25% yellow), M_3 (50% green and 50% yellow), M_4 (25% green and 75% yellow), and M_5 (100% yellow) and subjected to physico-chemical analysis. At eating soft stage, a significant linear increase in fruit juice percentage, total soluble solids (TSS), ripening index (TSS/TA) and fruit juice pH, while a decrease in rag content, ascorbic acid (vitamin C) and titratable acidity (TA) was observed as the maturity progressed from 100% green to 100% yellow. Sensory evaluation data of fruit skin colour, flavour, texture, and acceptability showed the highest score for fruits harvested at 25% green and 75% yellow (M4) stage. In conclusion, harvest maturity significantly influenced various biochemical quality characteristics and carambola fruits harvested at 75% yellow (M_4) is considered as an optimal harvest stage that exhibited best sensory and nutritional quality attributes.

Keywords: *Biochemical characteristics, fruit maturity, nutritional quality, star fruit.*

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INTRODUCTION

The agro-climatic conditions of Pakistan are congenial to produce several types of fruits. More than 35 fruits are grown in Pakistan and most of these are planted commercially as organized plantations, while several indigenous and exotic minor fruits are also grown. These minor fruits contain a greater amount of proteins, minerals, dietary fibres, carbohydrates, vitamins, bioactive compounds, and phytochemicals (Ménager et al., 2004; Gao et al., 2011; Shahnawaz and Sheikh, 2011). In the current era, food security is a critical concern for the ever-increasing population that results in increased food demand. Under such circumstances, besides major fruits, there is a need to explore minor fruits as the best option to fulfil per capita fruit consumption (200-250 g) per day per person (WHO, 2015). Among different minor fruits, carambola (*Averrhoa carambola* L.) is an emerging and highly nutritious exotic fruit crop in Pakistan. Despite its high nutritional value, its cultivation is on limited scale and restricted to gardens of Sindh and Punjab provinces (Khan and Shaukat, 2006). Fruit is normally oblong in shape with 5-6 angled-ribs, having 6-12 cm length and 6 cm width. Fruit colour varies from green to yellow golden with crunchy texture, juicy flavour, and a bit acidic in nature (Khan and Shaukat, 2006). The edible portion of the fruit is fleshy that contains greater amount of natural antioxidants like vitamin C, provitamin A and an excellent source of oxalic acid, sugars, minerals, and dietary fibres. It is consumed as both fresh or dessert, and processed into juices, wine, jam and jelly (Patil et al., 2010; Manda et al., 2012). Moreover, it possess multifaceted medicinal properties (anti-inflammatory, analgesic, hypotensive, anthelmintic and anti-tumour activity) along with various biological activities (Leelarungrayub et al., 2016).

There are lot of compositional changes that occur during fruit maturity and ripening which play an essential role in flavour development and can affect the sensory (e.g., sweetness, total acidity, pH) and chemical characteristics of the fruit (Mahmood et al., 2013; Nayab et al., 2020). At different maturity stages, a great variation in nutritional quality status have been observed in many fruits like orange, strawberry, persimmon, blueberry, and mulberry (Ayaz et al., 2001; Ramin and Tabatabaie, 2003; Sturm et al., 2003; Nayab et al., 2020). Mulberry fruits harvested at fully ripened stage showed more biochemical and bioactive compounds than semi-ripened fruits, indicating their suitability for fresh consumption (Nayab et al., 2020). Similarly, carambola fruit harvested at 80% maturity exhibited highest TSS value as compared to 60% and 70% maturity, while TA showed the reverse trend (Chen et al., 2017). Moreover, excellent fruit quality attributes were found in carambola cv. 'Arkin' fruits harvested at colour break stage as reported by Warren et al. (2007). Additionally, sensory evaluation indicated that fruit of carambola harvested at advanced maturity (50% golden colour)

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were preferred for fresh consumption than commercial maturity (Light green) (Pauziah et al., 2010). For this reason, the assessment of the physico-chemical properties of carambola fruits at different maturity stages is of great interest to the researchers for highlighting the nutritional quality of this minor fruit of the region. Although, carambola is grown in some pockets on a limited scale as ignored fruit, however the agro-climatic conditions of southern Punjab (Pakistan) are congenial for its production. Hence, this pilot study was conducted to determine the physico-chemical changes in carambola fruits harvested at five different maturity stages to quantify the nutritional quality characteristics.

MATERIALS AND METHODS

Fruits of carambola cultivar "Arkin" free from insect-pests, diseases and bruising were harvested from Saghir Naseem Farm, Manthar, Sadiqabad (28° 18' 2.304'' N; 70° 7' 48.828'' E) during September 2019 at five different maturity stages based on their fruit colour (Table 1, Fig. 1). After harvest, healthy fruits were properly packed in cardboard boxes and carried to the Postharvest Science and Technology Laboratory, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan for quality assessments under ambient conditions (25±2 °C; 55-60% RH). Each treatment was replicated thrice with five fruit per replication.

Samples preparation and physico-chemical analysis

Fruit samples were washed with distilled water to remove dust. After that, juice was extracted with a fruit juice extractor (Nowake N-999, Japan) for physico-chemical analysis. Juice content was weighed and recorded in grams by using the method given by Hussain et al. (2017). Juice and rag contents were expressed as percent. Total soluble solids (TSS) of fruit juice was determined in °Brix unit by using Abbe's Refractometer (NAR-IT, Japan) following the method given by Nayab et al. (2020). The pH of juice samples was recorded using calibrated digital pH meter (Jenway-350, England) by following the method described by Anwar et al. (2007). Titratable acidity (TA) of juice samples was determined by acid-base titration method following the protocol of Nayab et al. (2020) and expressed in % oxalic acid. Ripening index (TSS/TA) was calculated by dividing TSS of samples with their respective TA. Ascorbic acid content in juice samples was determined by using the method previously adopted by Naz et al. (2014).

Table 1: Detail of studied fruit maturity stages with their characteristics.

Stage name	Color characteristics
M_1	100% green
M_2	75% green; 25% yellow
M_3	50% green; 50% yellow
M_4	25% green; 75% yellow
M_5	100% yellow

Figure 1: Different maturity stages of carambola fruit.

Sensory evaluation

Sensory evaluation was performed by a ten-person panel consisting of university staff and students by adopting the method used by Mahmood et al. (2013). Panel was told to sort the fruit samples on a 9-point hedonic scale (1 = extremely dislike, 5 = neither like nor a dislike, 9 = extremely like), based on colour, flavour/taste, texture, and overall acceptability. Each panel member evaluated three fruit samples per replication of each maturity stage.

Statistical analysis

Data regarding each parameter were analysed statistically using computer-based software (Statistix 8.1), in which maturity stages were considered as treatments and triplicate determinations as replications using completely randomized design (CRD). Comparison of means was computed by applying LSD at $p < 0.05$.

RESULTS

Juice and rag content

In this study, results regarding juice and rag contents (%) of carambola fruits exhibited significant differences ($p<0.05$) among five different maturity stages as shown in Fig. 2A, B. A linear increase in juice content was observed in fruit samples with the advancement of fruit maturity, while rag content exhibited the decreasing trend. The highest juice content (49.9%) was recorded when fruits were harvested at M_5 (100% yellow) stage and the lowest juice content (41.2%) was measured at M_1 (100% green) stage. Fruits harvested at M_1 (100% green) stage had the highest rag content (58.8%), while the lowest rag content (50.1%) was recorded in the fruits harvested at M_5 (100% yellow) stage.

TSS, pH, TA, ripening index and ascorbic acid

The observations about juice TSS and pH of carambola fruits indicated a consistent rise as maturity progressed (Fig. 2C, D). According to the analysed data, the values of TSS (11.7 °Brix) and pH (3.2) were significantly higher ($p<0.05$) in fruits harvested at M_4 (25% green and 75% yellow) stage as compared with fruits harvested at early maturity stages. The lowest TSS and pH (7.5 °Brix and 2.8, respectively) were observed in fruits harvested at M_1 (100% green) stage. TA of carambola fruits dropped as maturity progressed. Significantly higher ($p<0.05$) TA was noted at early maturity stage M_1 (100% green) (1.6%) as compared with later stages (Fig. 2E). However, non-significant ($p>0.05$) difference was detected between the two later stages (M3 and M4). The lowest TA (0.6%) was observed in fruits harvested at M_5 (100% yellow) stage.

Different maturity stages of carambola fruit exhibited significant

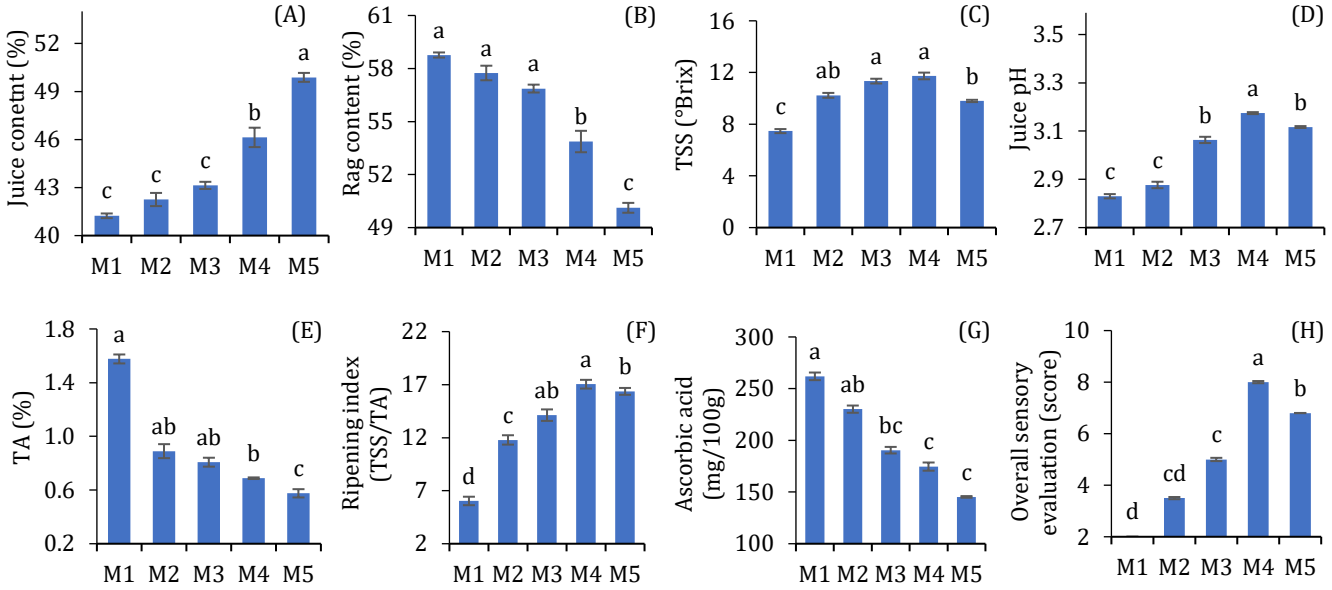

Figure 2: Changes in different quality parameters of carambola fruits with fruit maturity stages. The X-axis in each section indicates the maturity stages (M_1 = 100% green, M_2 = 75% green; 25% yellow, M_3 = 50% green; 50% yellow, M_4 = 25% green; 75% yellow, M_5 = 100% yellow). Different letters on graph bars indicate significant differences among maturity stages at $p \leq 0.05$. LSD ($p \leq 0.05$) values for juice content = 2.03, rag content = 2.21, total soluble solids (TSS) = 2.33, juice pH = 0.354, titratable acidity (TA) = 0.835, ripening index = 2.83, ascorbic acid = 55.02 and sensory evaluation = 1.59.

differences for ripening index (Fig. 2F). Among five different maturity stages, from M_1 to M_5, there was a linear increase in ripening index. The highest value of ripening index (17.36%) was recorded in fruits harvested at M_5 (100% yellow) stage, while the lowest ripening index (6.03%) was observed in fruits harvested at M_1 (100% green) stage. Changes in ascorbic acid content of fruits harvested at different maturity stages are shown in Fig. 2G. Ascorbic acid content was found higher (261.9 mg/100 mL) in fruits harvested at M_1 (100% green) stage but gradually declined with the increase in maturity stages. Final value of ascorbic acid was very low (145.3 mg/100 FW) for fruits harvested at M_5 (100% yellow) stage.

Sensory analysis

The impact of maturity stages on sensory characteristics (colour, texture, flavour, and acceptability) of fruit samples are collectively presented in Fig. 2H. As fruits undergo from un-ripened to full-ripened stages (M_1 to M_4), significant ($p<0.05$) increased in sensory attributes were noted by the panellists that later declined in fruit harvested at M5 stage (over ripened) (Table 2). However, highest score of sensory attributes including colour (9.00), flavour (7.67), texture (7.67) and acceptability (7.67) were recorded in fruit harvested at M4 than other stages (Table 2).

DISCUSSSION

From consumer point of view, crispy and juicy carambola fruits with a yellow colour peel, free from brown spots are preferred for fresh consumption. The taste of carambola fruits depends on the cultivar and fruit maturity stage (Kader, 2009). When the fruit ripens, the peel colour changes from green to yellow-green and then become yellow or orange as the carbohydrates and TSS increase and organic acids are reduced (Campbell, 1989). According to the results of our study, as the fruit maturity advanced, fruit juice content, TSS and ripening index of carambola fruit increased, while ascorbic acid decreased. Similar results have been reported by Pauziah et al. (2010) and Chen et al. (2017) in carambola fruits harvested at different maturity stages. TSS/TA ratio indicates the balance of sugars and acids that greatly impact the fruit taste. Fruit colour and taste have been designated as key parameter for determination of fruit quality (Voća et al., 2008). Acidity in carambola fruits is one of the important quality characters. Generally, acidity of fruits decreased as fruits advanced towards maturity. Decrease in TA with progress in maturity of fruits could be due to the use of organic acid content in fruit as respiratory substrate, and carbon skeletons for the formation of new compounds (Valderrama et al., 2005). Vitamins are considered as important hidden attributes that affect the consumption quality and hence,

Table 2: Effect of different maturity stages on sensory characteristics of carambola fruits.

Stage name	Color	Flavor	Texture	Acceptability
M_1	2.33^{c}	2.00^{d}	1.67^{d}	2.33^{d}
M_2	4.00^{bc}	3.00^{d}	3.67^{c}	3.33^{d}
M_3	5.33^{b}	4.67^{c}	5.33^{b}	4.67^{c}
M_4	9.00^{a}	7.67^{a}	7.67^{a}	7.67^{a}
M_5	7.67^{a}	6.00^{b}	7.33^{a}	6.33^{b}
LSD ($P \leq 0.05$)	1.431	1.024	1.191	1.104

Different superscript letters show the significant differences within columns for each parameter at ≤ 0.05 and n = 5 (maturity stages). M_1 = 100% green, M_2 = 75% green; 25% yellow, M_3 = 50% green; 50% yellow, M_4 = 25% green; 75% yellow, M_5 = 100% yellow.

consumer perception (Ramin and Tabatabaie, 2003). Among various vitamins, ascorbic acid is the most commonly measured nutrient in horticultural crops (Lee and Kader, 2000). In the climacteric fruit, during fruit ripening, ascorbic acid dissociates due to increased activity of ascorbic acid oxidase (Ramin and Tabatabaie, 2003). Similar findings have been reported in persimmons (Taira et al., 1987), tomato (Saltveit, 1999) and pineapple guava (García-Rivera et al., 2016).

The typical flavour and taste of fruit is usually associated with various sensory attributes including sweetness, acidity, astringency, and aroma. After analysing the data for sensory parameters (flavour, appearance, texture), the carambola fruits harvested at M4 (25% green and 75% yellow) maturity stage were appreciated the most by the panellists. Similar findings have been reported by Pauziah et al. (2010), who stated that carambola fruits harvested at an advanced maturity stage showed excellent eating quality with attractive yellow colour. Fruit at advanced maturity were more appealing for fresh consumption than fruit harvested at early stages, as more mature fruits were sweeter with less astringency, and a better overall taste.

CONCLUSION

In conclusion, the ripening of carambola fruits was associated with a softening of the flesh, an increase in TSS and pH and a decrease in TA and ascorbic acid contents. Considering the changes in different biochemical parameters, fruits harvested at M4 (75% yellow) maturity stage were found the best for eating quality along with high nutritional profile.

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