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Effect of harvesting and storage conditions on the post harvest quality and shelf life of mango (*Mangifera indica* L.) fruit

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Abstract

The impact of harvest stages and storage conditions over the postharvest quality of mango (Langra and Samar Bahisht Chaunsa) varieties has been investigated. The fruit was harvested at 80 (early stage), 95 (mid stage) and 110 (late stage) days after the fruit setting and designated as samples I, II, and III, respectively. The harvested fruit was stored under three different storage conditions till its ripening. Significant variations were observed in quality characteristics by varying harvest stage, storage conditions and their combinations. The contents of vitamin C and acidity were highest in sample I and sugar contents in sample III of the fruit. The weight loss was highest and shelf life was longest for sample I and waste percentage was lowest for sample II. The waste percentage, weight loss, pH, total soluble solids, carotenoids and total sugar increased the percentage of acidity and vitamin C was decreased with storage time/ripening process, irrespective of maturity stages. The ripening rate was increased and the shelf life was decreased with the increase in storage temperature. The skin color, total soluble solids, sugar contents and carotenoids were well correlated.

Keywords: Maturity stage; Quality; Storage temperature; Shelf life

1. Introduction

Mango (*Mangifera indica* L.) fruit belongs to dicotyledonous family of Anacardiaceae and is known as "king of fruits" (Nunes et al., 2007). It is nutritious, having an excellent flavor, attractive fragrance, and delicious taste (Pal, 1998). It is commercially grown in more than 80 countries of the world and Pakistan stands at 5th position, with the production of 938 kt, sharing 7.6% in the world market (Sauco, 2002). Mango is a climacteric fruit, generally harvested at mature green stage, and ripens up during the marketing process (transport, storage etc.). However, due to the application of conventional technology for the transfer of the produce and an irregular storage period more than 30% is wasted (Carrillo et al., 2000; Narayana et al., 1996; Shahbaz et al., 2009). The variation in pre- and post-harvest factors affect the quality and contribute in providing strong heterogeneous batches of mangoes in terms of fruit size, gustatory quality, essential nutrients, vitamins and minerals, in the supply chain and effect the post harvest management (Jacobi et al., 1995; Lalel et al., 2003; Nunes et al., 2007). However, the most damaging factors are attack of microorganisms, improper harvesting time (maturity), ripening conditions and lack of suitable storage facilities. These factors can also cause a glut during the peak harvesting period and a large portion of the yield is either wasted or sold very cheap. Further, the designing of non-destructive technology for the evaluation of quality of the fruit that has recently became very popular and requires precise information about the relationship between organoleptic characteristics and sugar contents, carotenoids, and total soluble solids of the fruits. The organoleptic characteristics are also very important for the marketing of the fruit (Al-Haq and Sugiyama, 2004a; Butz, et al., 2005; Jha, 2006; Jha et al., 2005, 2007, 2010; Lebrun et al.,

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2008; Mizrach et al., 1997; Santulli and Jeronimidis, 2006). Therefore, scientists are working hard and proposing various techniques to minimize the wastage (Abbasi et al., 2009; Anwar and Malik, 2007; Hoa et al., 2002; Lurie, 1998; Maqbool and Malik, 2008) and the outcome is not very promising and needs systematic efforts (Lechaudel et al., 2010; Saranwong et al., 2004; Shafique et al., 2006; Subedi et al., 2007). Though Langra and Samar Bahisht Chaunsa mango varieties are of high quality, little has been reported over these cultivars (Akhtar et al., 2010; Anwar and Malik, 2007; Jha et al., 2010). The reduction in post-harvest losses, suitable harvesting stage of fruit (maturity) and optimum ripening conditions to have the best quality and longer shelf life has not been recognized in developing countries. This study was conducted to find the optimum stages of maturity and ripening conditions that ensure better quality for fresh consumption and long distance marketing. For the purpose, the fruit was harvested at 80, 95 and 110 days after the fruit setting and stored at 20, 30 and 40 °C till its ripening. The fruit was analyzed at the harvest time as well as at ripened stage. The results obtained were evaluated with reference to harvest days and storage temperature over the quality, shelf life and waste percentage of the fruit.

2. Materials and methods

The experiments were performed over Langra and Samar Bahisht Chaunsa (S.B. Chaunsa) mango varieties during the years 2008–2010. The fruit was harvested randomly from Government Fruit Nursery Farm, Agriculture Extension Department, Dera Ismail Khan, Pakistan. It was harvested carefully by hand at 80 (early stage), 95 (mid stage) and 110 (late stage) days after the fruit setting and referred as samples I, II, and III, respectively. The fruit was cleaned properly to remove all the foreign matters such as dust, dirt etc. Maximum efforts were made to select the fruit uniform in size, good in quality and free from injury or disease. The harvested fruit was analyzed and stored in well ventilated wooden boxes at Department of Chemistry, Gomal University, Dera Ismail Khan, Pakistan. The storage temperature was kept at 20, 30 and 40 °C while the relative humidity (RH) was 80%, 64% and 58%, respectively. Two hundred fifty numbers of mangoes were selected for each variety and test. Each analysis was carried out thrice and the data was presented as the average of the repeated analysis over the 3 years time. Mangoes were analyzed for different parameters at harvest as well as at the ripened stage. The two factor experiment was laid out in Completely Randomized Design (CRD) with three replications. The aroma, taste and flavor of all the samples were measured using Hedonic scale (Larmond, 1987). A panel of 21 experts whose age was 20–45 years was made on their consistency and reliability of judgment. Twenty-one mango fruits of each sample were selected randomly and were cut into six pieces. The material so obtained was equally divided among the experts. Panelists were asked to score the difference between samples by allotting the numbers from 0 to 10 (0–2 means extremely disliked, 2–4 fair, 4–6 good 6–8 very good and greater than 8 means excellent aroma, taste and flavor). The skin color of mango samples was measured with a colorimeter (Chroma Meter CR-300, Minolta Co. Ltd., Japan). Four evenly distributed places along the equator were selected and a mean value was used. The values obtained were scaled according to Hedonic scale for comparison purpose (Larmond, 1987): 0–2 meant green, 2–4 light green, 4–6 light yellow, 6–8 yellow and 8–10 full yellow. Measurements of firmness were taken with a Bosch penetrometer (model FT 327). The firmness was determined by the force (g mm^{-2}) necessary for a 2 mm probe to puncture the fruit peel at four different points and taking average of the values (external firmness). The values obtained were rescaled according to Hedonic scale for comparison purpose (Larmond, 1987); 10–8 meant firm, 8–6 slightly soft, 6–4 soft, 4–2 were over soft.

The moisture contents were calculated by taking 10 g of fruit pulp and drying in an oven up to constant weight at 76 °C and calculating the loss in weight (AOAC, 2000). pH value was measured using a Microprocessor pH meter supplied by Denver, USA. The total titratable acidity was determined by titrating 100 mL of juice against (0.1 N) sodium hydroxide (AOAC, 2000). Total soluble solids and total sugar were measured from the mixed pulp using digital refractometer (Atago-Palette PR 101, Atago Co. Ltd., Itabashi-Ku, Tokyo, Japan). For the estimation of total solids (TS), 30 g of the mixed fresh sample of pulp was dried in an oven at 76 °C and TS was obtained (AOAC, 2000). The contents of ascorbic acid were determined by titrating 10 g of mixed pulp sample against the standard 2, 6 dichlorophenol dye following the procedure outlined in (AOAC, 2000). Total carotenoids of pulp were estimated following the method of (Anwar and Malik, 2007) and were expressed as μg/g of β-carotene equivalent from a standard curve of β-carotene. The weight of the fruit for both the varieties was measured at the harvest and at the ripened stage, using Mattler electronic balance. The weight loss percent was calculated for each samples and storage temperature based over this data. The ripened stage of the fruit was detected through the variation in firmness and sugar contents (Shorter and Joyce, 1998). The fruit was considered as waste when it was infected by the disease and/or its firmness value was less than 4. Each value was expressed as the mean ± standard error (SE) of three independent experiments. Data were assessed by analysis of variance (ANOVA) and Duncan's multiple range tests to identify statistical significance.

3. Results and discussion

3.1. Organoleptic characteristics

The results obtained for organoleptic characteristics at the harvest time were low while firmness was high (Table 1). All the parameters were increased except firmness during the ripening process and were high for high storage temperature (Table 2), indicating that the fruit was ripened with the passage of time. The decrease in green color was the most obvious change in mango and was attributed to an increase in carotenoids pigments during the storage and the principal agent responsible for such variations may be the oxidative system, pH change and enzymes like chlorophyllases (Doreyappy-Gowda and Huddar, 2001). With the ripening of fruit, the concentration of volatile compounds was increased and made the fruit more attractive, delicious and valuable (Al-Haq and Sugiyama, 2004b; Bender et al., 2000;

Table 1
The average (±SE) values of organoleptic parameters measured at harvest time for Langra and Samar Bahisht Chaunsa mango fruit, harvested at different days after setting of the fruit.

Variety	Samples	Harvest days	Color	Firmness	Aroma	Taste	Flavor
Langra	I	80	0	10	0	0	0
	II	95	0.5±0.02	9.5±0.21	0.5±0.05	0.2±.01	0.3±.02
	III	110	1.5±.0.03	9.0±0.18	1.0±0.05	1.0±0.07	1.0±0.1
S.B. Chaunsa	I	80	0.6±0.02	9.3±0.21	0.6±.0.05	0.21±.01	0.3±.02
	II	95	0.9±.0.03	9.2±0.18	1.02±0.05	1.1±0.07	1.2±0.1
	III	110	1.8±0.02	8.7±0.23	1.5±.0.05	1.2±.01	2.3±.02

Kays, 1991; Malundo et al., 1996). The firmness results indicated that the fruit was intact and hence had good look even at ripened stage as observed by others for other varieties (Al-Haq and Sugiyama, 2004b; Mizrach et al., 1997; Santulli and Jeronimidis, 2006). The results for the fruit taste illustrated that it was developed during the ripening process. As the taste is a combination of sugar and acids present in the fruit, it was expected that the sugar contents were increased and the acid value was decreased with the passage of time (Kays, 1991; Malundo et al., 2001). The organoleptic characteristics were lowest for 20 °C and highest for 40 °C storage temperature. This trend was attributed to the fact that the ripening of mango fruit is characterized by loss of firmness due to cell wall digestion by pectinesterase, polygalacturonase, and other enzymes and this process was increased by the increase in storage temperature (Narain et al., 1998). The statistical analysis made in this respect concluded that the measured parameters are significantly different for sample as well as storage temperature (Table 2).

3.2. pH

The pH measured at the harvest time and at the ripened stage concluded that it was highest for sample III stored at 40 °C and lowest for sample I stored at 20 °C, irrespective of variety (Tables 3, 4a, and 4b).These observations were attributed to the conversion of citric acid and ascorbic acid into sugar and other products with the ripening process and whose rate of conversion was increased with the temperature (Absar et al., 1993; Kumar and Singh, 1993; Rathore et al., 2007; Yuniarti, 1980). The pulp pH obtained at ripened stage for different samples was significantly different at the level of $P<0.05$ limit.

3.3. Moisture contents

The moisture contents which were high at the harvest time were decreased with the ripening process and were low for lower storage temperature and vise-versa. These were high for Langra as compared to Samar Bahisht Chaunsa throughout the measurements (Tables 3, 4a, and 4b). This trend was expected as in case of low storage temperature the ripening rate is expected to be low and the fruit required longer time and vice-versa. In addition, the moisture contents move from the inner side of the fruit to outer side for the escape purpose (mass transfer) and it takes place through diffusivity phenomenon which is enhanced with the ripening of the fruit (Dissa et al., 2011). It was also noted that the moisture contents were highest for sample III and lowest for sample I. The high quality of fruit in case of sample III was attributed to the fact that the fruit

Table 2
The average (±SE) values of organoleptic parameters measured at ripened stage for Langra and Samar Bahisht Chaunsa mango fruit stored at different temperatures.

V*	S	ST	Color	Firmness	Aroma	Taste	Flavor
Langra S.B. Chaunsa	I	20	3.07^{h+}±0.09	5.01^{g}±0.25	3.71^{h}±0.11	4.02^{h}±0.12	4.01^{h}±0.12
		30	5.03^{g}±0.25	5.81^{f}±0.30	5.02^{g}±0.25	5.82^{g}±0.29	5.71^{g}±0.30
		40	5.38^{f}±0.27	6.18^{e}±0.32	5.49^{f}±0.28	6.02^{f}±0.30	6.02^{f}±0.30
	II	20	5.01^{g}±0.25	6.13^{e}±0.31	5.41^{f}±0.27	6.01^{f}±0.30	6.01^{f}±0.30
		30	7.10^{d}±0.36	7.14^{c}±0.36	7.43^{d}±0.37	7.69^{d}±0.39	7.61^{d}±0.39
		40	7.41^{c}±0.37	7.49^{b}±0.37	7.64^{c}±0.38	8.16^{c}±0.41	8.02^{c}±0.41
	III	20	6.11^{e}±0.31	6.89^{d}±0.34	6.54^{e}±0.33	7.01^{e}±0.35	7.01^{e}±0.35
		30	8.19^{b}±0.41	7.61^{b}±0.38	8.44^{b}±0.42	8.61^{b}±0.44	8.46^{b}±0.42
		40	8.51^{a}±0.43	8.01^{a}±0.40	8.63^{a}±0.43	9.14^{a}±0.46	8.84^{a}±0.44
S.B. Chaunsa	I	20	4.02^{h}±0.12	5.42^{g}±0.27	4.04^{h}±0.12	4.74^{h}±0.14	4.71^{h}±0.14
		30	6.07^{g}±0.30	6.02^{f}±0.30	5.71^{g}±0.30	6.01^{g}±0.31	5.91^{g}±0.30
		40	6.43^{f}±0.32	6.44^{e}±0.32	6.11^{f}±0.31	6.41^{f}±0.32	6.39^{f}±0.31
	II	20	6.01^{g}±0.30	6.38^{e}±0.32	6.08^{f}±0.30	6.42^{f}±0.32	6.41^{f}±0.31
		30	8.01^{d}±0.40	7.41^{c}±0.37	7.81^{d}±0.38	8.01^{d}±0.40	8.01^{d}±0.40
		40	8.38^{c}±0.41	7.71^{b}±0.39	8.24c±0.40	8.42c±0.42	8.41c±0.42
	III	20	7.21^{e}±0.36	7.01^{d}±5.35	7.09^{e}±0.35	7.43^{e}±0.37	7.41^{e}±0.37
		30	8.62^{b}±0.44	7.72^{b}±0.38	8.51^{b}±0.42	8.86^{b}±0.45	8.61^{b}±0.43
		40	9.21^{a}±0.46	8.08^{a}±0.40	9.02^{a}±0.45	9.41^{a}±0.47	9.01^{a}±0.45

+Values having different superscript in the columns for the same variety are significantly different under the limit of $P<0.05$.
* V, S and ST stand for variety, samples, storage temperature (°C), respectively.

spent more time on tree and received more nutrition and water as compared to others (Farquhar et al., 1980; Hollinger, 1996; Simmons et al., 1998). The statistical analysis concluded that the results obtained for different samples were significantly different at the level of $P<0.05$ limit.

3.4. Total soluble solids

The total soluble solids (TSS) were increased with the ripening process and were high in case of high storage temperature, irrespective of sample/variety of the fruit (Tables 3, 4a, and 4b). The increase in TSS was the outcome of conversion of carbohydrates into simple sugars through a complex mechanism during the storage and the conversion rate was increased with the increase in temperature. This conversion is also considered to be one of the important indexes of ripening process in mango and other climacteric fruit (Doreyappy-Gowda and Huddar, 2001; Kays, 1991; Kittur et al., 2001). It was concluded that the total soluble solids and skin color had good positive correlation and can be used as an indicator for the judgment of quality of the fruit, without destroying (Fig. 1). The results obtained for the fruit harvested at different stages were significantly different under the limit of $P<0.05$.

3.5. Total solids

The values of total solids were decreased with the harvest stage as well as storage temperature, irrespective of the variety (Tables 3, 4a, and 4b) and the results were according to expectations (Saranwong et al., 2004; Subedi et al., 2007).

3.6. Total sugar

The sugar contents of the mango (Langra and Samar Bahisht Chaunsa) varieties were recorded at the time of harvest as well as at the ripened stage (Tables 3, 4a, and 4b). It was noted that the sugar contents were highest for sample III and lowest for sample I at the harvest time and was attributed to the fact that the sample III spent more time on the tree as compared to others (Table 3). The results obtained at the ripened stage concluded that the sugar contents were lowest for sample I stored at 20 °C and highest for sample III stored at 40 °C for both the varieties. Further to it, the contents were high for S.B. Chaunsa variety for a particular sample or storage temperature. The plausible explanation for such trend is that the polysaccharides were converted into soluble sugar through hydrolytic conversion process, which was sensitive to temperature and/or to sunlight exposure for climacteric fruits during the ripening process (Campestre et al., 2002; Kays, 1991; Martinez et al., 1997). The application of ANOVA to the data concluded that the results for different samples and storage temperatures were significantly different under the limit of $P<0.05$.

3.7. Total carotenoids

The analysis of the harvested fruit indicated that the total carotenoids were increased with the harvest stage or storage temperature during the ripening process, irrespective of the variety; it was high for S.B. Chaunsa as compared to Langra (Tables 3, 4a, and 4b) (Chuadhary, 2006). During the ripening process, the transition of chlorophyll into carotenoids, biochemical conversions of starch into sugar, insoluble protopectin into pectin and loss of organic acid through oxidation are responsible for the increase in sugar and carotenoids (Campestre et al., 2002; Kays, 1991; Martinez et al., 1997). Therefore, the high quality of fruit in case of sample III was attributed to the fact that the fruit spent more time on tree and hence was exposed to sun for longer time and received more nutrition (Farquhar et al., 1980; Hollinger, 1996; Simmons et al., 1998). The statistical application (ANOVA) to the data concluded that the results obtained for various harvest stages were significantly differed under the limit of $P<0.05$. The skin color of the fruit showed nice positive correlation with the carotenoids and sugar contents, irrespective of storage temperature and harvest stage (Figs. 2 and 3) and can be used as an indicator for the quality/ripening stage of mango fruit without destroying (Ornelas-Paz et al., 2008).

3.8. Acidity

The acidity was lowest for sample III for a particular storage temperature and was decreased with the increase in storage temperature for both the varieties. The acidity was more in Langra than in Samar Bahisht Chaunsa variety at the harvest as well as at the ripened stage, irrespective of storage conditions (Tables 3, 4a, and 4b). The decrease in acidity was attributed towards the conversion of citric acid into sugars and their further

Table 3
The average (±SE) values of chemical constituents of Langra and Samar Bahisht Chaunsa mango fruit, measured at harvest time.

V *	S	Total sugar (g/kg)	TC (g/kg) × 10^3	A (g/kg)	AA (g/kg)	pH	MC (g/kg)	TSS (g/kg)	Total solids (g/kg)
Langra	I	$25.1^{c\,+}\pm0.8$	$15.11^{c}\pm0.76$	$37.1^{a}\pm1.1$	$369.75^{a}\pm18.75$	$2.01^{c}\pm0.06$	$691.3^{c}\pm35.0$	$43.1^{c}\pm1.3$	$298.7^{a}\pm14.9$
	II	$34.5^{b}\pm1.1$	$24.98^{b}\pm1.25$	$29.1^{b}\pm0.9$	$299.73^{b}\pm15.12$	$2.98^{b}\pm0.09$	$772.2^{b}\pm39.4$	$63.6^{b}\pm1.9$	$227.8^{b}\pm11.4$
	III	$48.6^{a}\pm1.5$	$30.18^{a}\pm1.51$	$21.1^{c}\pm0.6$	$240.63^{c}\pm12.12$	$3.55^{a}\pm0.11$	$821.2^{a}\pm41.0$	$81.5^{a}\pm2.5$	$178.8^{c}\pm8.9$
S.B. Chaunsa	I	$27.1^{c}\pm0.8$	$22.22^{c}\pm1.12$	$2.9.4^{a}\pm0.9$	$315.77^{a}\pm16.35$	$2.21^{c}\pm0.07$	$681.1^{c}\pm34.0$	$40.1^{c}\pm1.2$	$318.9^{a}\pm15.9$
	II	$43.5^{b}\pm1.3$	$35.18^{b}\pm1.79$	$19.9^{b}\pm0.6$	$220.71^{b}\pm11.12$	$3.11^{b}\pm0.09$	$754.1^{b}\pm38.0$	$60.2.0^{b}\pm1.8$	$245.0^{b}\pm12.3$
	III	$57.5^{a}\pm0.1.7$	$59.56^{a}\pm2.97$	$13.9^{c}\pm0.4$	$170.61^{c}\pm8.85$	$3.61^{a}\pm0.11$	$800.1^{a}\pm41.0$	$74.9^{a}\pm2.3$	$199.9^{c}\pm9.9$

+Values having different superscript in the columns for the same variety are significantly different under the limit of $P<0.05$.
* V, S, TC, A, AA, MC and TSS stand for variety, samples, total carotenoids, acidity, ascorbic acid, moisture contents and total soluble solids, respectively.

Table 4a
The average (±SE) values of chemical constituents measured at ripened stage for Langra mango fruit, stored at different temperatures.

*S	ST	TSu	TC×10^3	A	AA	pH	MC	TSS	TS
I	20	133.6^{h+}±6.8	32.31^i±1.64	8.6^a±0.25	124.67^a±6.23	3.95^i±0.11	572.9^i±28.7	148.2^i±7.4	427.1^a±2.14
	30	161.2^g±8.2	40.32^h±2.05	7.5^b±0.25	114.68^b±5.73	4.05^h±0.12	581.0^h±29.1	174.1^h±8.7	419.0^b±2.09
	40	172.5^f±8.9	45.32^g±2.3	7.2^c±0.23	109.45^c±5.47	4.12^g±0.13	601.1^g±30.1	181.1^g±9.1	408.9^c±1.23
II	20	182.1^e±9.2	51.41^f±2.62	6.2^d±0.2	94.51^d±4.73	4.86^f±0.14	677.6^f±33.9	19.8.4^f±9.9	322.4^d±1.61
	30	210.2^d±11.0	58.40^e±2.98	5.2^e±0.16	85.5^e±4.28	4.96^e±0.15	684.5^e±34.2	220.5^e±11.3	315.5^e±.5.8
	40	220.1^c±11.2	62.40^d±3.18	4.9^f±0.15	82.11^f±4.11	5.01^d±0.15	691.2^d±34.6	230.5^d±11.5	308.8^f±15.4
III	20	220.2^c±11.0	63.22^c±3.16	5.3^g±0.17	80.54^g±4.03	5.45^c±0.16	715.6^c±35.8	234.5^c±11.6	284.4^g±14.2
	30	250.1^b±12.4	74.33^b±3.72	4.4^h±0.13	72.53^h±3.63	5.61^b±0.17	722.5^b±36.1	261.1^b±.3.4	277.5^h±13.9
	40	266.5^a±13.1	78.09^a±3.96	4.1^i±0.13	69.38^i±3.47	5.78^a±0.18	730.1^a±36.5	267.5^a±13.1	269.9^i±13.5

*S, TSu, TC, A, AA, MC TSS and TS stand for samples, total sugar, total carotenoids, acidity, ascorbic acid, moisture contents, total soluble solids and total solids, respectively; all the quantities are expressed in g/kg.
+Values having different superscript in the columns for the same variety are significantly different under the limit of $P<0.05$.

Table 4b
The average (±SE) values of chemical constituents measured at ripened stage for Samar Bahisht Chaunsa mango fruit, stored at different temperatures.

*S	ST	TSu	TC×10^3	A	AA	pH	MC	TSS	TS
I	20	151.1^i±7.7	53.26^i±2.67	6.3^a±0.2	102.48^a±5.12	4.10^i±0.12	597.1^i±29.9	166.9^i±8.3	402.9^a±20.1
	30	182.5^h±9.2	59.79^h±3.05	5.3^b±0.16	93.38^b±4.67	4.19^h±0.13	604.2^h±30.2	199.1^h±9.9	395.8^b±19.8
	40	191.1^g±9.6	62.77^g±3.20	5.0^c±0.15	90.76^c±4.54	4.26^g±0.14	616.1^g±30.8	201.2^g±10.1	383.9^c±19.2
II	20	201.2^f±9.2	69.21^f±3.12	4.7^d±0.14	80.41^d±4.02	5.19^f±0.16	656.8^f±32.8	214.2^f±10.7	343.2^d±17.2
	30	231.4^e±11.6	77.81^e±3.97	3.7^e±0.2	71.31^e±3.57	5.27^e±0.17	662.7^e±33.1	241.1^e±12.1	337.3^e±16.9
	40	240.5^d±12.3	81.62^d±4.14	3.4^f±0.11	68.28^f±3.41	5.34^d±0.16	674.1^d±33.7	2.0.1^d±12.5	325.9^f±16.3
III	20	242.2^c±12.0	84.12^c±4.21	3.9^g±0.13	66.39^g±3.32	5.84^c±0.18	696.1^c±34.8	254.5^c±12.7	283.9^g±14.2
	30	272.1^b±13.6	95.72^b±4.89	3.0^h±0.10	58.28^h±2.91	6.08^b±0.19	702.1^b±35.0	276.2^b±13.8	297.9^h±14.9
	40	283.1^a±1.38	99.22^a±4.99	2.7^i±0.9	55.28^i±2.76	6.25^a±0.20	712.8^a±35.6	285.1^a±1.43	289.9^i±14.5

+Values having different superscript in the columns for the same variety are significantly different under the limit of $P<0.05$.
* S, TSu, TC, A, AA, MC TSS and TS stand for samples, total sugar, total carotenoids, acidity, ascorbic acid, moisture contents, total soluble solids and total solids, respectively; all the quantities are expressed in g/kg.

utilization in metabolic process of the fruit (Doreyappy-Gowda and Huddar, 2001; Mizrach et al., 1997; Rathore et al., 2007; Srinivasa et al., 2002). It was interesting to note that carotenoids, sugar and acidity had nice negative correlation, indicating that with the ripening of the fruit the acidity was decreased while carotenoids and sugar was increased (Fig. 2).

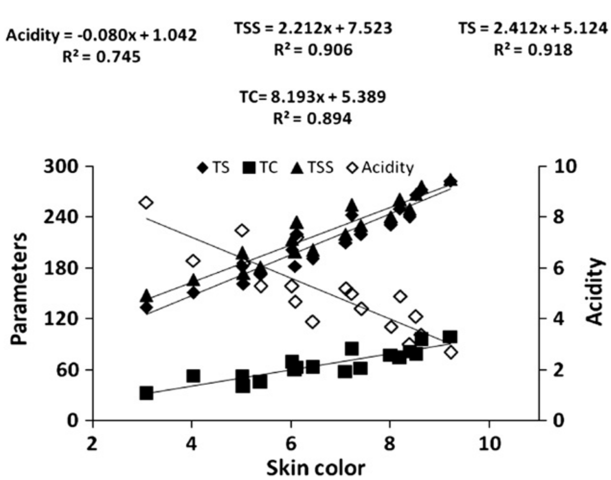

Fig. 1. Correlation of acidity (g/kg), total carotenoids (TC×10^3 (g/kg)), total sugar (TS (g/kg)) and total soluble solids (TSS (g/kg)) with the skin color of both the varieties, irrespective of sample and storage temperature.

3.9. Ascorbic acid

The contents of ascorbic acid (vitamin C) for Langra and Samar Bahisht Chaunsa mango varieties were recorded at the time of harvest for every harvest stage concluded that it was high for sample I as compared to sample II or III (Table 3). The value

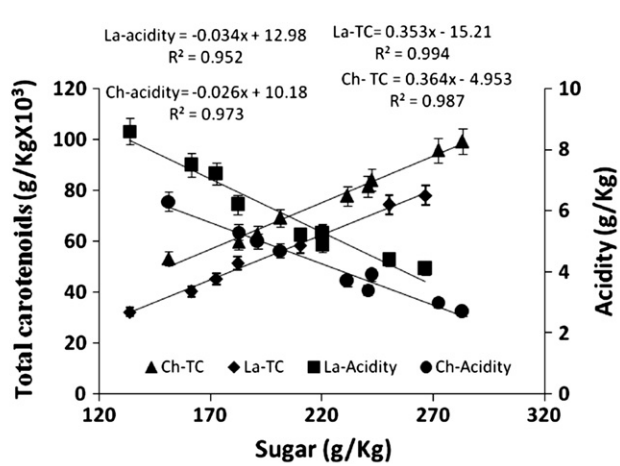

Fig. 2. Correlation of acidity and total carotenoids with sugar for both the varieties, irrespective of sample and temperature; La, Ch and TC stand for Langra, Samar Bahisht Chaunsa and total carotenoids, respectively.

was decreased with the ripening of the fruit or with the increase in storage temperature, irrespective of the variety (Tables 4a and 4b). This trend was due to conversion of acid into sugars and their further utilization in metabolic process of the fruit and that the chemical and biological process was increased with the increase in storage temperature (Doreyappy-Gowda and Huddar, 2001; Mizrach et al., 1997; Rathore et al., 2007; Srinivasa et al., 2002). The ascorbic acid was high for Langra as compared to S.B. Chaunsa, irrespective of sample or storage temperature and was comparable to Shindhu variety at the ripened stage (Absar et al., 1993).

3.10. Ripening days

The time required for ripening of the fruit obtained for different samples/storage temperature concluded that the shelf life of mango fruit was longest for sample I stored at 20 °C and shortest for sample III stored at 40 °C. The results were significantly different for samples as well as storage temperature under the limit of $P<0.05$ (Fig. 3). The trend was explained in terms of high the storage temperature faster the respiration rate and the fruit needed less time to ripen up.

3.11. Waste percent

The waste percent of the fruit calculated during the storage period was least for sample II stored at 30 °C and the results were significantly different under the limit $P<0.05$ (Fig. 4). These observations indicated that stage II was an optimum condition for harvesting the fruit and the enzymatic/chemical reactions which were going on before harvest lead to proper ripening of the fruit. Similarly, 30 °C storage temperature provides sufficient energy to the system to properly proceed the ripening. It was concluded that the harvest days (sample number) and the storage temperature had noticeable impact over the shelf life, waste percent and quality of the fruit.

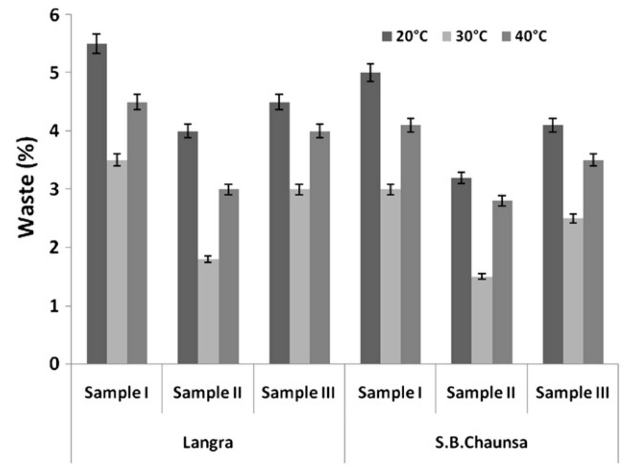

Fig. 4. Waste percent of the fruit during the ripening process.

3.12. Activation energy

Since every chemical or biological process needs certain amount of activation energy and this energy plays very important role not only in ripening of the fruit but also in its spoilage. Therefore, the ripening rate was plotted versus storage temperature (Fig. 5) and the activation energy as per Arrhenius equation (Eq. (1)) was calculated (Mut et al., 2008).

$$\text{Ripening rate} = \text{K}e^{-\text{Ea}/\text{RT}} \tag{1}$$

Here K, Ea, R and T are pre-exponential factor, activation energy, gas constant and storage temperature in Kelvin scale. The activation energy so obtained was plotted for different samples in Fig. 6. It was noted that the activation energy was not significantly different for sample I and II for both the varieties; however, it was high for sample III, concluding that with the passage of time the biological process becomes more complicated and needs high energy.

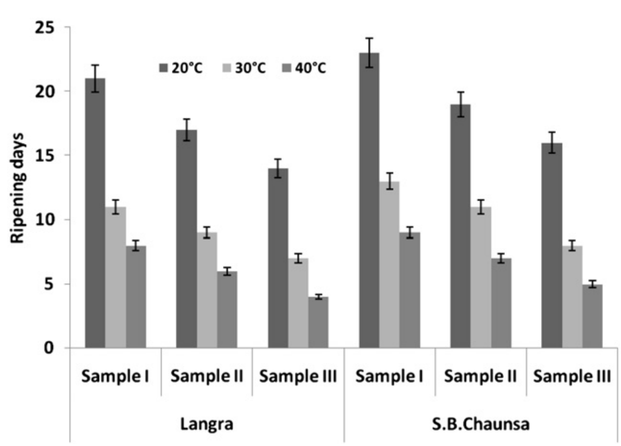

Fig. 3. Time required by the fruit to reach at the ripened stage as a function of storage temperatures.

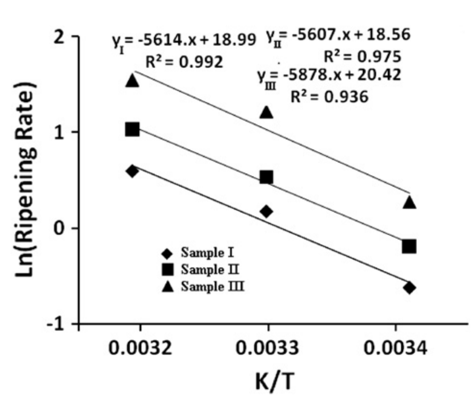

Fig 5. Ripening rate (=change in sugar contents/days) of different samples of S.B. Chaunsa variety as a function of storage temperature.

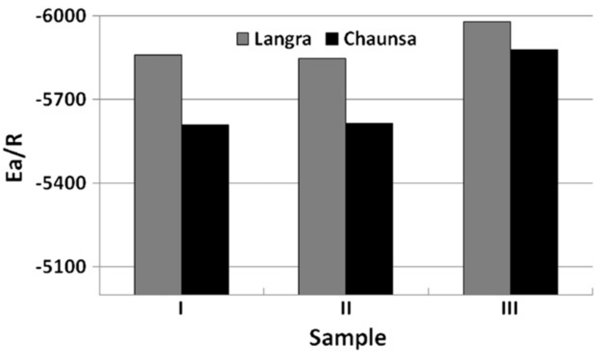

Fig 6. Activation energy of Langra and S.B. Chaunsa varieties.

4. Conclusions

It was noted that the total soluble solids, sugar, carotenoids and skin color had quite high positive and acidity has negative correlation. The application of ANOVA to the results obtained concluded that the effect of harvest days and storage temperature was quite significant. It was observed that sample III was better in quality but had shorter shelf life as compared to others. Further, the mango samples stored at 40 °C had high quality but shortest shelf life. The waste percent was lowest for sample II at 30 °C as compared to other samples as well as storage temperature. In case of sample I, the shelf life was longest amongst all but the quality was not so good. It was also noted that though the ripening rate of Langra was high, the quality of S.B. Chaunsa was better. The ripening rate of the fruit concluded that the activation energy was high for Langra as compared to S.B. Chaunsa.

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References

Abbasi, N.A., Iqbal, Z., Maqbool, M., Hafiz, A.I., 2009. Post harvest quality of Mango (*Mangifera indica* L.) Fruit as affected by chitosan coating. Pakistan Journal of Botany 41, 343–357.

Absar, N., Karim, M.R., Amin, M.A.L., 1993. A comparative study on the changes in the physic-chemical composition of ten varieties of mango in Bangladesh at different stages of maturity. Bangladesh Journal of Agriculture Research 18, 201–208.

Akhtar, S., Naz, S., Sultan, T.M., Mahmood, S., Nasir, M., Ahmad, A., 2010. Physico-chemical attributes and heavy metal Content of mangoes (*Mangifera indica* L.) Cultivated in different regions of Pakistan. Pakistan Journal of Botany 42, 2691–2702.

Al-Haq, M.I., Sugiyama, J., 2004a. Measurement of firmness of Irwin mangoes by a non-destructive acoustic tester during cold storage. Transactions of ASAE 47, 2017–2021.

AL-Haq, M.I., Sugiyama, J., 2004b. Application of electrolyzed water in food processing. Presented at ASAE/CSAE annual meeting, Ottawa, Canada, August 1–4, 2004 ASAE paper No.04-6178.

Anwar, R., Malik, A.U., 2007. Hot water treatment affects ripening quality and storage life of mango (*Mangifera indica* L.). Pakistan Journal of Agriculture Science 44, 304–311.

AOAC, 2000. Official Methods of Analysis. Association of Official Analytical Chemist, Arlington, VA.

Bender, R.J., Brecht, J.K., Baldwin, E.A., Maludo, T.M.M., 2000. Aroma volatiles of mature-green and tree-ripe ‘Tommy Atkins’ mangoes after controlled atmosphere vs air storage. Horticulture Science 35, 684–686.

Butz, P., Hofmann, C., Tauscher, B., 2005. Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. Journal of Food Science 70, R131–R141.

Campestre, C., Marsilio, V., Lanza, B., Iezzi, C., Bianchi, G., 2002. Phenolic compounds and organic acids change in black oxidized table olives. ISHS Acta Hort. 586: IV International Symposium on Olive Growing. ISBN: 978-90-66057-56-2.

Carrillo, L.A., Ramirez-Bushtamant, F., Valdez-Torres, J.B., Rojas-Villages, R., Yahi, E.M., 2000. Ripening and quality changes in mango fruit as affected by coating with an edible film. Journal of Food Quality 23, 479–486.

Chuadhary, M.T., 2006. Carotenoids pigments of different varieties of mangoes; changes during ripening. Journal of the Science of Food and Agriculture 1, 173–177.

Dissa, A.O., Desmorieux, H., Degrave, P., Bathiebo, J., Koulidiati, J., 2011. Impact of fruit ripeness on physiochemical properties and convective drying characteristics of Kent mango (*Mangifera indica* L. cv. Kent). International Journal of Food Engineering 7 (Article 12).

Doreyappy-Gowda, I.N.D., Huddar, A.G., 2001. Studies on ripening changes in mango (*Mangifera indica* L.) fruits. Journal of Food Science and Technology Mysore 38, 135–137.

Farquhar, G.D., Von Caemmerer, S., Berry, J.A., 1980. A biochemical model of photosynthetic CO2 assimilation in leaves in C3 species. Planta 149, 78–90.

Hoa, T.T., Ducamp, M.N., Lebrun, M., Baldwin, E.A., 2002. Effect of different coating treatments on the quality of mango fruit. Journal of Food Quality 25, 471–486.

Hollinger, D.Y., 1996. Optimality and nitrogen allocation in a tree canopy. Tree Physiology 16, 627–634.

Jacobi, K.K., Wong, L.S., Giles, J.E., 1995. Effect of fruit maturity on quality and physiology of high humidity hot air treated ‘Kensington’ mango (*Mangifera indica* L). Postharvest Biology and Technology Engineering 78, 22–26.

Jha, S.S., 2006. Non-destructive determination of firmness and yellowness of mango during growth and storage using visual spectroscopy. Biosystem Engineering 94, 397–402.

Jha, S.N., Chopra, S., Kingsly, A.R.P., 2005. Determination of sweetness of intact Mango using visual spectral analysis. Biosystem Engineering 91, 157–161.

Jha, S.N., Chopra, S., Kingsly, A.R.P., 2007. Modeling of color values for nondestructive evaluation of maturity of mango. Food Engineering 78, 22–26.

Jha, S.N., Narsaiah, K., Sharma, A.D., Singh, M., Bansal, S., Kumar, R., 2010. Quality parameters of mango and potential of non-destructive techniques for their measurement - a review. Journal of Food Science and Technology 47, 1–14.

Kays, S.J., 1991. Post harvest Phys. of Perishable Plant Products. Vas Nostr and Rein Hold Book. AVI Publishing Co., pp. 149–316.

Kittur, F.S., Saroja, N., Habibunnisa, N., Tharanathan, R.N., 2001. Polysaccharide-based composite coating formulations for shelf-life extension of fresh banana and mango. European Food Research and Technology 213, 306–311.

Kumar, P., Singh, S., 1993. Effect of GA3 and ethrel on ripening and quality of mango CV. Amarpali. Horticulture Journal 6, 19–23.

Lalel, H.J.D., Singh, Z., Tan, S.C., 2003. Maturity stage at harvest affects fruit ripening, quality and biosynthesis of aroma volatile compounds in ‘Kensington Pride’ mango. Journal of Horticulture Science and Biotechnology 78, 225–233.

Larmond, E., 1987. Methods for sensory evaluation of foods. Publ. No. 1637Department of Agriculture, Ottawa, Canada.

Lebrun, M.A., Plotto, K., Goodner, M.N., Ducamp, M.N., Baldwin, E., 2008. Discrimination of mango fruit maturity by volatiles using the electronic nose and gas chromatograph. Postharvest Biology and Technology 48, 122–131.

Lechaudel, M., Urban, L., Joas, J., 2010. Chlorophyll Fluorescence, a nondestructive method to assess maturity of Mango fruits (Cv. ‘Cogshall’) without growth conditions Bias. Journal of Agriculture Food Chemistry 58, 7532–7538.

Lurie, S., 1998. Post harvest heat treatments. Postharvest Biology and Technology 14, 257–269.

Malundo, T.M.M., Baldwin, E.A., Ware, G.O., Shewfelt, R.L., 1996. Volatile composition and interaction influence flavor properties of mango (*Mangifera indica* L.). Processing Florida State Horticulture Society 109, 264–268.

Malundo, T.M.M., Shewfelt, R.L., Ware, G.O., Baldwin, E.A., 2001. Sugars and acids influence flavor properties of mango (*Mangifera indica* L). Journal of the American Society for Horticulture Science 126, 115–121.

Maqbool, M., Malik, A., 2008. Anti-Sap chemicals reduce sap burn injury and improve fruit quality in commercial mango cultivars. International Journal of Agriculture and Biology 10, 1–8.

Martinez, B.E., Guevara, C.G., Contreras, J.M., Rodriguez, J.R., Lavi, U., 1997. Preservation of mango Azucar variety (*Mangifera indica* L.) at different storage stages: Proceedings of the fifth international mango symposium (Tel Aviv, Israel, 1996), 2, pp. 747–754.

Mizrach, A., Flitsanov, U., Fuchs, Y., 1997. An ultrasonic non destructive method for measuring maturity of mango fruit. Transactions of ASAE 40, 1107–1111.

Mut, P., Bustamante, C., Martínez, G., Alleva, K., Sutka, M., Civello, M., Amodeo, G., 2008. A fruit-specific plasma membrane aquaporin subtype PIP1; 1 is regulated during strawberry (Fragaria × ananassa) fruit ripening. Physiologia Plantarum 132, 538–551.

Narain, N., Bora, P.S., Narian, R., Shaw, P., 1998. Mango. In: Shaw, P.E., Chan, H.T., Nagy, S. (Eds.), Tropical and Subtropical Fruits. Agrscience, Inc., Auburndale, FL, pp. 1–77.

Narayana, K., Pal, R.K., Roy, S.K., 1996. Effect of pre-storage treatments and temperature regimes on shelf life and respiratory behaviour of ripe Beneshan mango. Journal of Food Science and Technology Mysore 33, 79–82.

Nunes, C.N., Emond, J.P., Bredcht, J.K., Dea, S., Prooulx, E., 2007. Quality curves for mango fruit stored at chilling and non chilling temperatures. Journal of Food Quality 30, 104–120.

Ornelas-Paz, J.J., Yahia, E.M., Garde, A.A., 2008. Changes in external and internal color during postharvest ripening of 'Manila' and 'Ataulfo' mango fruit and relationship with carotenoids content determined by liquid chromatography-APcI ± time of flight mass spectrometry. Postharvest and Biology and Technology 50, 145–152.

Pal, R.K., 1998. Ripening and rheological properties of mango as influenced by ethrel and calcium carbide. Journal of Food Science and Technology Mysore 35, 358–360.

Rathore, H.A., Masud, T., Sammi, S., Soomro, A.H., 2007. Effect of storage on physico-chemical composition and sensory properties of Mango (*Mangifera indica* L.) variety Dosehri. Pakistan Journal of Nutrition 6, 143–148.

Santulli, C., Jeronimidis, G., 2006. Development of a Method for Nondestructive Testing of Fruits using Scanning Laser Virometry NDT.net Sep 2006, vol. 11 No. 10. Centre for Biomimetics, University of Reading, UK.

Saranwong, S., Sornsrivichai, J., Kawano, S., 2004. Prediction of ripe-stage eating quality of mango fruit from its harvest quality measured nondestructively by near infrared spectroscopy. Postharvest Biology and Technology 31, 137–145.

Sauco, V.G., 2002. Mango: emerging tropical export crop. Chronicle Horticulture 42, 14–17.

Shafique, M.Z., Ibrahim, M., Helali, M.O.H., Biswas, S.K., 2006. Studies on the physiological and biochemical composition of different mango cultivars at various maturity levels. Bangladesh Journal of Science and Research 41, 101–108.

Shahbaz, M., Iqbal, Z., Saleem, A., Anjum, M.A., 2009. Association of Lasiodiplodia Theobromae with different decline disorders in Mango (*Mangifera Indica* L.). Pakistan Journal of Botany 41, 359–368.

Shorter, A.J., Joyce, D.C., 1998. Effect of partial pressure infiltration of calcium into 'Kensington' mango fruit. Australian Journal of Experimental Agriculture 38, 287–294.

Simmons, S.L., Hofman, P.J., Whiley, A.W., Hetherington, S.E., 1998. Effects of pre-harvest calcium sprays and fertilizers, leaf:fruit ratios, and water stress on mango fruit quality. In: Coates, L.M., Hofman, P.J., Johnson, G.I. (Eds.), International Workshop on Disease Control and Storage Life Extension in Fruit. Australian Centre for International Agricultural Research, Chiang Mai, pp. 19–26.

Srinivasa, P., Baskaran, C.R., Ramesh, M.N., Prashantand, K.V.H., Tharanthan, R.N., 2002. Storage studies of mango Packed using biodegradable Chitosan film. European Food Research and Technology 215, 504–508.

SubedI, P.P., Walsh, K.B., Owens, G., 2007. Prediction of mango eating quality at harvest using short-wave near infrared spectrometry. Postharvest Biology Technology 43, 326–334.

Yuniarti, 1980. Pysico-chemical changes of Arumanis mangoes during storage at ambient temperature. Bulletin Penelition Horticulture Indonesia 8, 11–17.

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