Influence of different desapping agents on the incidence of sapburn, ripening behaviour and quality of mango

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Abstract Sapburn injury in mango is regarded as the most serious problem as it reduces the aesthetic appeal and down-grades the fruit quality with considerable economic losses. For the control of sapburn injury, physiologically mature mango fruits of cv. Chausa were harvested along with 5–8 cm stalk attached. Immediately after harvesting, fruits were destemmed and treated with different desapping agent solutions [calcium hydroxide (1 %), sodium hydroxide (1 %), alum (0.5 and 1 %)] by dipping them for 5 min. In control fruits, the pedicels were removed and sap was allowed to spread freely over the fruit surface. After treatment application, fruits were air-dried and stored at ambient condition (30 ± 2 °C) for 12 days. Among the treatments, fruits desapped with sodium hydroxide (1 %) showed significantly lower (7.6-fold) sapburn injury followed by alum (0.5 %) treatment than control. Respiration and ethylene evolution rates were also significantly suppressed and delayed with sodium hydroxide (1 %)

treatment. Fruit firmness and functional properties like, antioxidant capacity, total carotenoids and total phenolics content were also found higher in sodium hydroxide (1 %) treated fruits. Pectin methyl esterase and polygalacturonase enzyme activity were recorded higher in fruits of control and calcium hydroxide treatment however; it was suppressed by sodium hydroxide and alum treatments. Fruit quality parameters like color, total soluble solids, titratable acidity and total sugars content were found higher in calcium hydroxide and sodium hydroxide treated fruits than control and alum treated fruits.

Keywords Mango · Sapburn · Firmness · Antioxidant capacity · Functional quality · Enzyme activity

Introduction

Mango (*Mangifera indica* L.) is considered one of the most popular fruit among million of people across the globe, particularly in India where it is deemed to be the preferred of all indigenous fruits. Because of its delicious taste and appealing aroma, it is ranked as one of the popular fruit in the national and international market. India is the largest producer of mango in the world accounting for more than 50 % of total mango production worldwide, but remains world's third largest exporter. The mango industry faces several challenges, from the very beginning during harvesting to postharvest management including pest and disease attack, limited shelf-life of fruit and quality issues. One of such major quality concerns for mango producers and exporters is sapburn, which results in poor cosmetic quality fruits thus lowers the price of fruit especially in international markets (Bosquez et al. 2000). In common with other members of the Anacardiaceae family, mango plants have an extensive system of ducts both in the fruit and stem (Joel 1980). The sap contained in the fruit ducts remains under considerable pressure and when the pedicel is

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broken at the abscission zone during harvesting of fruit, the sap exude out and deposited on the fruit surface causing sapburn or sap-injury. The injury is characterized by brownish-black to black streaks or blotches on the skin of mango due to its acidic nature (Loveys et al. 1992). Symptoms may not appear at the initial contact but become vividly distinct after few hours or as fruit ripening progresses. Apart from the skin damages, the fruit peel color development also seems to be interfered by the sticking of sap. Moreover, the sap also attracts soil particles and microorganisms towards it due to its sugary and sticky nature, subsequently become a site for secondary infections which further reduces the storage life of the fruit by causing quick decay (Campbell 1992). Ultimately, the fruit quality is affected negatively, degrading the cosmetic appeal, reducing consumer acceptance, storage life and finally resulting in high economic losses.

The mango sap exudes out from fruit is basically composed of two parts: an oil fraction and an aqueous fraction (O'Hare and Prasad 1991). Oil fraction is yellow-brown in color, has raw mango like aroma and represented about 10 % of total sap volume. A major component of this oil fraction is terpinolene, which is mainly responsible for the symptoms of sapburn injury as it makes contact with and enters the mango skin *via* the lenticels (O'Hare and Prasad 1991). The aqueous milky and viscous fraction is protein-polysaccharide in nature and its ability to cause injury is much lower than the oil fraction. The sap is highly acidic and is responsible for the allergic reaction when come in contact with the human skin (Loveys et al. 1992). The browning of sapburn injured fruit is mediated by polyphenol oxidase (PPO) and laccase enzymes present both in the sap and fruit peel. The PPO enzyme activity is higher in sap from ripe mango compared to unripe fruit (Menezes et al. 1995). The incidence of sapburn injury ranges from a low of 5 % to a high of 50 %, varying in magnitude among cultivars, lenticels density, tree age, fruit maturity (the less mature the fruit, the more sap it exudes), growing regions and conditions under which harvesting take place (Lim and Kuppelweiser 1993). Besides that, the time of the day when harvesting has done also influence sapburn injury. There is greater sap flow early in the morning than latter during the day which is due to the high water content or turgor pressure that decreased as the day temperature increased (Amin et al. 2008). With the increase in temperature the rate of transpiration from the fruit surface increases, which ultimately results in reduction of water concentration in mango fruit sap and when the concentration of water is reduced, the terpinolene oil concentration is more which is the real cause of sapburn severity (Barman et al. 2011a).

Various approaches have been reported to avoid the problem of sapburn injury in mango including: de-sapping on the ground, on special de-sapping racks and trays by keeping the fruit in inverted position, or on conveyor belts or machines

(Ledger 1991; Meurant 1991). Various chemicals have also been tested to control the sapburn injury including sodium carboxymethyl cellulose, lauryl sulphate sodium, calcium hydroxide solutions and dabbing with vegetable oil, waxes and powder, de-sapping in commercial detergent, chlorsan, agral (Landrigan et al. 1991; Baker 1991). However, their effects on ripening behavior and fruit quality have not been studied in detail. Looking into the importance of fruit and problems faced by growers/traders during marketing, the main objective of this experiment was to evaluate effect of some potential desapping agents on sapburn injury reduction, and their effects on mango fruit quality during storage at ambient condition.

Materials and methods

Plant materials and treatments

Mango fruits (cv. Chausa) were harvested at physiological maturity stage (light cream pulp with 8–10⁰ Brix TSS) along with 5–8 cm stalk attached from the orchard of Indian Agricultural Research Institute, New Delhi. Immediately after harvesting fruits were taken to the handling and storage laboratory and uniform sized healthy fruits free from visual blemishes, pests and diseases were selected for the experiment. Then the fruits were subjected to different desapping treatments with calcium hydroxide (1 %), sodium hydroxide (1 %), alum (0.5 %), alum (1 %) solutions and control. While desapping, first the fruit pedicels were cut back and were dipped immediately in the treatment solutions for 5 min, whereas in case of control, the pedicels were removed and sap was allowed to spread freely over the fruit surface. After giving treatments, the fruits were air-dried and stored at ambient condition (30±2 °C, 75–80 % RH) for 12 days. The experiment was conducted with five treatments and three replications. Total 225 fruits were selected for the experiment and divided into 5 lots of 45 fruits each for the treatments (3 replications and 3 fruits per replication).

Physiological loss in weight

In order to determine physiological loss in weight (PLW), both treated and untreated fruits were weighed at different sampling intervals of 0, 3, 6, 9 and 12 days after treatment. Then PLW was calculated as the difference between the initial weight of the fruit and the weight of the fruit at time of measurement and expressed as percentage (% of initial weight of the fruit).

Sapburn injury

The incidence of sapburn injury was assessed using sapburn injury score ranging from 0 to 4 based on common visual

symptoms (Maqbool et al. 2007). The score used was: 0=no injury, 1=very mild (injury area $<1\text{ cm}^2$), 2=mild (injury area $\geq 1 < 2\text{ cm}^2$), 3=moderate (injury area $\geq 2 < 4\text{ cm}^2$), 4=severe (injury area $\geq 4\text{ cm}^2$). The sapburn injury score was calculated by multiplying the number of fruits in each category by the respective score, summing the products and dividing by the total number of fruits.

Fruit firmness

Fruit firmness was determined individually using a probe coupled to a Texture Analyzer (model: TA+Di, Stable micro systems, UK) through penetrations and the measurement of the force required for a probe (2 mm diameter) to penetrate 10 mm inside fruit. The probe was advanced at a speed of 2 mm s^{-1} after contacting the mango peel until it was ruptured. Three puncture force measurements were made on three equatorial fruit zones at intervals of 90° angle and the results were expressed in newton (N).

Respiration and ethylene evolution rates

Respiration rate was measured by placing fruit in a 1 l capacity container hermetically sealed with a silicone rubber septum for 1 h. After specified time, the head-space gas was sucked through a hypodermic hollow needle and the respiration rate was quantified by using auto gas analyzer (model: Checkmate 9900 O_2/CO_2 , PBI Dansensor, Denmark) and results were expressed in milliliters of CO_2 released per kg of fruit per hour ($\text{ml CO}_2\text{ kg}^{-1}\text{ h}^{-1}$). Ethylene evolution rate was determined by a gas chromatograph (model: Hewlett Packard 5890 Series II, USA) equipped with a flame ionization detector (FID) and Porapack-N 80/100 mesh packed stainless steel column. The temperature of injector, column and detector were adjusted to 110°C , 60°C and 275°C and flow rate of N_2 , H_2 and air were maintained as 30, 30 and 300 ml min^{-1} , respectively. The rate of ethylene evolution was expressed as microliters of ethylene released per kg of fruit per hour ($\mu\text{l kg}^{-1}\text{ h}^{-1}$).

Total carotenoids, antioxidant capacity and total phenolics content

Total carotenoids content was determined by extracting carotenoids from fruit pulp with a mixture of petroleum ether and acetone (3:1) and assayed colorimetrically by spectrophotometer at 452 nm (Roy 1973). The results were expressed as $\text{mg } 100\text{ g}^{-1}\text{ FW}$ (fresh weight) basis. Total phenolics content of the fruit extracts were determined by the Singleton and Ross method (1965), and expressed in microgram of gallic acid equivalent per gm of fruit ($\mu\text{g GA equiv. g}^{-1}\text{ FW}$). Antioxidant capacity was determined by following cupric reducing antioxidant capacity (CUPRAC)

method (Apak et al. 2004) and results were expressed as $\mu\text{mol Trolox equiv. g}^{-1}\text{ FW}$.

Pectin methyl esterase (PME) and Polygalacturonase (PG) activity

Pectin methyl esterase (PME) activity was measured by the method of Hagerman and Austin (1986), and expressed as $(0.328 \times \Delta A_{620} - 0.003)\text{ }\mu\text{mol min}^{-1}\text{ g}^{-1}\text{ FW}$. Polygalacturonase (PG) activity was measured following the method of Lazan et al. (1989), and expressed as $(288.07 \times \text{O.D.})\text{ }\mu\text{g galacturonic acid g}^{-1}\text{ h}^{-1}\text{ FW}$.

Fruit quality parameters

Fruit peel color was determined using the Hunter Lab System (model: Miniscan XE PLUS). The results were expressed as L^* (0: dark, 100: white), a^* (negative value: green, positive value: red) and b^* (negative value: blue, positive value: yellow) values as the means of three determinations for each fruit along the equatorial axis. Total soluble solids (TSS) concentration was determined using FISHER hand refractometer at 20°C and results were expressed as degree Brix ($^\circ\text{B}$). Titratable acidity (TA) was determined by using titration method (AOAC 2000). To do that, 2 g of fruit sample was grounded to 100 ml distilled water plus a few drops of phenolphthalein solution as indicator and titrated with 0.1 N sodium hydroxide up to pH 8.1. The results were expressed as percentage citric acid (%). Total sugars content was determined by the method described by AOAC (2000) by taking a known quantity of fruit pulp, using lead acetate to remove excess of lead free aliquot were examined by titrating against boiling Fehling's solution, which had previously been standardized using methylene blue indicator. The results were expressed in percentage (%).

Statistical analysis

The data obtained from three replicates under different treatments in respect to various parameters during storage were subjected to analysis of variance (ANOVA) with treatment and storage time as sources of variation. Mean comparison among treatments were performed using the HSD Tukey's test at a significance level of $p < 0.05$. All analyses were performed with SPSS software package version 16.0 for windows.

Results and discussion

Physiological loss in weight

The physiological loss in weight (PLW) was found increased continuously with the advancement of storage

period up to 12 days (Fig. 1). However, all the treatments significantly influenced the physiological loss in weight. Among different treatments, the PLW was least (16.6 %) in sodium hydroxide (1 %) treated fruits, followed by alum (0.5 %), while it was highest (18.4 %) in control fruits at the end of the storage period. Desapping with sodium hydroxide reduced the PLW ≈ 11 % during storage, as compared to control.

Physiological loss in weight in mango fruit during storage is mainly due to evaporation of water from the fruit. The peel thickness of mango also showed decreased gradually with the advancement of storage period (data not shown). This finding also supports the loss of moisture from the fruit peel. Among the treatments, fruits treated with sodium hydroxide and alum showed much lower PLW as compared to calcium hydroxide and control. The solution of sodium hydroxide (1 %) was slimy in nature, so it might provided a physical coating that prevented the loss of moisture from the fruit. Furthermore, control and calcium hydroxide treated fruits showed occurrence of anthracnose and stem-end rot diseases, and the severity was much higher compared to

NaOH and alum treated fruits. The onset of these diseases further aggravated the loss of moisture by tissue disruption and breakdown of cell integrity thus, allowing transference of water vapour to the external atmosphere. Besides that, lower respiration rate in sodium hydroxide treated fruits might have also contributed to lower weight loss (Valero et al. 1998). Previous works on pomegranate also support this finding (Barman et al. 2011b; Elyatem and Kader 1984).

Sapburn injury

The effect of treatments on sapburn injury of mango revealed that all the treatments were highly effective in reducing the injury, and the symptoms were found increased with the duration of storage or as the ripening progresses (Fig. 1). However, the application of sodium hydroxide (1 %) and alum (0.5 and 1 %) showed significantly lower fruit sapburn injury as compared to calcium hydroxide (1 %) and control. Among the treatments, lowest sapburn injury score (0.50) was observed with sodium hydroxide (1 %) treatment (7.6-fold lower than control) followed by those

Fig. 1 Effect of different desapping agents on physical and physiological quality parameters in mango fruit during storage at ambient condition (30 ± 2 °C, 75–80 % RH). Data are means $\pm$ Standard error of three replicate determination ($n=3$). [T₁ Control, T₂ Calcium hydroxide (1 %), T₃ Sodium hydroxide (1 %), T₄ Alum (0.5 %), T₅ Alum (1 %)]

treated with alum (0.5 %) as compared to control (3.80), 12 days after storage period.

The mango sap exudes out from the fruit is highly acidic in nature with a pH=4.3 (John et al. 2003). The onset and severity of sapburn injury increased with ripening, during storage at ambient temperature. Similarly Maqbool and Malik (2008) also reported that sapburn injury symptoms increased as the ripening progress. This is because, the activity of PPO enzyme increases with the onset of ripening (Menezes et al. 1995). In the present study, all the treatments were highly effective in reducing the severity of sapburn injury in mango. Among the treatments, sodium hydroxide (1 %) was found to be most effective. It is a strong base with a pH of 13.2 and is widely used as an inexpensive alkali for peeling of fruits and in the manufacture of paper, textiles, drinking water, detergents etc. Calcium hydroxide (1 %) is also a strong alkali with a pH 12.4, widely used in many industrial processes. Therefore, these treatments might be reduced the sapburn injury by neutralizing the mango sap which is strongly acidic. The superiority of sodium hydroxide (1 %) was probably due to more basic nature than calcium hydroxide (1 %), thus posses more capability to neutralize acidic sap. Similarly, treatment with alum (0.5 and 1 %) also showed better result next to sodium hydroxide (1 %) which acts by coagulating the mango sap thus preventing the injury. Previous work on banana also showed coagulating property of alum on latex (Mortuza and Hag 1996). Furthermore, the symptoms might be reduced because alum contains sulphur, which act as inhibitor of polyphenol oxidase (PPO) enzyme which is mainly responsible for browning of sapburn injured fruit. Mortuza and Hag (1996) also reported inhibitory action of alum on PPO enzyme in banana.

Fruit firmness

The fruit firmness decreased progressively with the increase in storage period under all the treatments up to the end of the experiment (Fig. 1). However, this declining trend was much pronounced in control and calcium hydroxide treated fruits. Initially up to 3 days of storage period, there were no significant differences in fruit firmness among the treatments. Later, fruits treated with sodium hydroxide (1 %) and alum (0.5 %) retained significantly higher fruit firmness over other treatments and control. At the 12th day of storage, sodium hydroxide (1 %) treated mango fruits maintained $\approx$ 36 % higher fruit firmness as compared to control fruits.

Fruit firmness is an important characteristic which governs the postharvest life of fresh horticultural produce. In this study, lower firmness in untreated and calcium hydroxide treated mango fruits may be ascribed to these being metabolically more active, having higher respiration and ethylene evolution rates, as a result of which such fruits tend to soften at a faster rate. Higher firmness in sodium

hydroxide and alum treated fruits might be due to their lower metabolic activities, rendering them to be less soft or firmer. Besides that, higher activity of cell wall degrading enzymes (PME and PG) with the increase in storage period, in control and calcium hydroxide treated mango fruits promoted fruit softening and senescence process rapidly. On the other hand, fruits desapped with sodium hydroxide and alum showed significantly lower PME and PG activity which indicate the reason of maintaining higher fruit firmness.

Respiration and ethylene evolution rates

The data on respiration and ethylene evolution rates showed that all the treatments significantly suppressed the rate of respiration and ethylene evolution (Fig. 1). A typical respiratory climacteric peak was observed at 6th day of storage in control and calcium hydroxide (1 %) treated mango fruits however, this peak was delayed up to 3 days and even much lower with sodium hydroxide (1 %) and alum (0.5 and 1 %) treatments *i.e.* peak was observed at 9th day of storage. The respiratory climacteric peak was suppressed by 1.6, 1.48, 1.37 and 1.4 fold respectively with sodium hydroxide (1 %), alum (0.5 %), alum (1 %) and calcium hydroxide (1 %) treatments. At the end of the experiment, highest respiration rate ($148.6 \text{ ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$) was recorded under control and the lowest ($104.8 \text{ ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$) being with sodium hydroxide (1 %) treatment. The climacteric peak of ethylene was found significantly suppressed and delayed by 250, 160, 145 and 43 % with sodium hydroxide (1 %), alum (0.5 and 1 %) and calcium hydroxide (1 %) treatments respectively. After 12 days of storage, fruits treated with sodium hydroxide (1 %) showed lowest ($0.340 \text{ } \mu\text{l kg}^{-1} \text{ h}^{-1}$) ethylene evolution rate and highest ($1.577 \text{ } \mu\text{l kg}^{-1} \text{ h}^{-1}$) being in control.

In this study, respiration and ethylene evolution rate was significantly suppressed and delayed with the sodium hydroxide (1 %) treatment. This lower respiration rate might be attributed to reduced gas interchange and consequently lower oxygen availability to the fruit tissues due to physical barrier provided by sodium hydroxide treatment. Furthermore, the ripening process was found delayed with sodium hydroxide and alum treatment which support the delaying of ethylene and respiratory climacteric peak. On the other hand, comparatively early and higher respiration and ethylene evolution rate in control and calcium hydroxide treated fruits was possibly due to occurrence of diseases in those fruits. Earlier report also support the disease mediated increase in respiration and ethylene evolution rate (Fallahi 1997). A relationship between high calcium content and ethylene production has been suggested in melon (Madrid et al. 2004), so it could be assumed that desapping fruit with calcium hydroxide might have induced ethylene evolution resulted in accelerated ripening.

Total carotenoids content

The data on total carotenoids content revealed that, irrespective of treatments there was a continuous increasing trend in total carotenoids content up to 12 days of storage (Fig. 2). Initially fruits treated with calcium hydroxide contained higher carotenoids ($11.9 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) up to 9th day of storage period, as compared to other treatments and control ($10.2 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$). But at 12th day of storage, there was no significant difference in total carotenoids content between calcium hydroxide and sodium hydroxide treated fruits. At the end of the experiment, calcium hydroxide and sodium hydroxide treated fruits retained $\approx 14\%$ higher total carotenoids as compared to untreated fruits.

Total carotenoids content usually increases as fruit ripening process is advanced, and increase in carotenoids content has a direct relation with the change in fruit peel color from green to yellow, as the major coloring pigment is β -carotene. Hence, calcium hydroxide treatment enhanced the fruit ripening

process resulting in higher total carotenoids content and faster change in fruit color. Previous work of Maqbool and Malik (2008) also supported this finding. However, fruits treated with sodium hydroxide (1 %) and alum (0.5 and 1 %) showed slower development of carotenoids and changes in fruit color which supports the delaying of ripening process. Alum has antioxidant activity due to presence of sulphur compound so, owing to antisenescence property it might have delayed the ripening process which in turn lowered the respiration and ethylene evolution rates. Thus fruits treated with alum showed lower carotenoids content and much slower development of color up to end of the experiment.

Total phenolics content and antioxidant capacity

The result on total phenolics content depicts that, with the increase in storage period, the total phenolics content decreased continuously under all the treatments (Fig. 2). However, untreated and calcium hydroxide treated mango fruits

Fig. 2 Effect of different desapping agents on biochemical quality parameters in mango fruit during storage at ambient condition ($30 \pm 2^\circ \text{C}$, 75–80 % RH). Data are means $\pm$ Standard error of three replicate determination ($n=3$). [T_1 Control, T_2 Calcium hydroxide (1 %), T_3 : Sodium hydroxide (1 %), T_4 Alum (0.5 %), T_5 Alum (1 %)]

showed much rapid decline in total phenolics content than sodium hydroxide and alum treated fruits. Sodium hydroxide treatment maintained significantly higher total phenolics content from the initial days of storage and maintained it up to end of the experiment. At 12th day of storage, sodium hydroxide treated fruits recorded to contain ≈ 39 % higher total phenolics content than control fruits. In respect to antioxidant capacity, initially a sharp increase was recorded under all the treatments, the maximum being on 6th day of storage and thereafter a declining pattern was found (Fig. 2). However, this initial increase in antioxidant capacity was much higher in all the treated fruits than control, maximum (736.5 μmol Trolox equiv. g^{-1} FW) under sodium hydroxide (1 %) treatment. After 12 days of storage, highest antioxidant capacity (590.6 μmol Trolox equiv. g^{-1} FW) was retained in fruits treated with sodium hydroxide (1 %) followed by alum (0.5 %) than other treatments and control (340.2 μmol Trolox equiv. g^{-1} FW).

Antioxidant capacity of plant produce is mainly contributed by the presence of pigments, vitamins and polyphenolic compounds (Barman et al. 2011c). The reason for higher retention of antioxidant capacity in sodium hydroxide treated mango fruits might be explained by higher content of carotenoids and phenolics compounds. Kulkarni et al. (2004) also reported that phenolic compounds are responsible for antioxidant capacity in fruits. In this experiment, phenolic compounds are showed to decline continuously which is attributed to the natural process of ripening. The reduction in total phenolics content with the onset of ripening is a well known phenomenon (Briante et al. 2002). However higher total phenolics content in sodium hydroxide and alum treated fruits might be attributed to delay in ripening process.

Pectin methyl esterase (PME) and Polygalacturonase (PG) activity

The data on enzymatic activity (PME and PG) revealed that, the activity increased progressively with the advancement of storage period. In general, the activity was found significantly higher in untreated mango fruits compared to those treated with different desapping chemicals. A sharp increase in PME activity was found after 6 days of storage in control and calcium hydroxide treated mango fruits (Fig. 2). Among the different treatments, the lowest (0.28 $\mu\text{mol min}^{-1} \text{g}^{-1}$ FW) PME activity was recorded in sodium hydroxide treated fruits, followed by those (0.30 $\mu\text{mol min}^{-1} \text{g}^{-1}$ FW) treated with alum (0.5 %) 12 days after storage. In PG activity, up to 3 days of storage no significant difference was found among the treatments (Fig. 2). However, after 3rd day marked increase in PG activity was recorded. Untreated and calcium hydroxide treated fruits showed significantly higher activity up to end of the storage. On the other hand, sodium hydroxide and alum (0.5 %) treated fruits showed

lower activity compared to control and other treatments. At the end of the experiment, highest PG activity (79.0 μg galacturonic acid $\text{g}^{-1} \text{h}^{-1}$ FW) was recorded in control fruits while, it was lowest (65.5 μg galacturonic acid $\text{g}^{-1} \text{h}^{-1}$ FW) in sodium hydroxide treated fruits.

PME and PG are considered the most important cell wall degrading enzymes in softening of fruits (Abu-Sarra and Abu-Goukh 1992). In the present study, a continuous increase in PME and PG activity with the advancement of storage period has been recorded which is in agreement with the previous study of Ali et al. (2004) in mango. Higher enzymatic activity in untreated mango fruits might be attributed to progressive decrease in fruit firmness and advancement of senescence stage, due to disease incidence.

Fruit quality parameters

Fruit peel color is the most important quality parameter of mango fruit which influence consumer appeal as well as internal pulp color. Mango fruits treated with sodium hydroxide and alum exhibited reduced chromaticity (L^* , a^* and b^*) values during ripening (Table 1). Fruits treated with calcium hydroxide (1 %) showed faster color development as compared to other treatments and control. Rapid increase in a^* and b^* values in calcium hydroxide treated fruits indicated destruction of green color and development of yellow color respectively. The development of color was significantly suppressed by alum (1 %) treatment however; it was delayed by sodium hydroxide (1 %) treatment. At the end of experiment, higher L^* (64.4 ± 0.848), a^* (0.93 ± 0.166) and b^* (36.0 ± 0.548) value was recorded in calcium hydroxide treated fruits while it was lowest L^* (60.8 ± 0.666), a^* (-3.3 ± 0.199) and b^* (32.8 ± 0.800) in alum (1 %) treated fruits.

The total soluble solids (TSS) content increased rapidly in all the treatments up to 12 days of storage at ambient condition (Table 2). Up to 6th day of storage, rapid increase in TSS content was recorded in calcium hydroxide ($22.1 \pm 0.43^\circ\text{B}$) and untreated ($20.9 \pm 0.46^\circ\text{B}$) fruits. However from 9th day of storage, calcium hydroxide and sodium hydroxide treated fruits showed higher content of TSS compared to other treatments and control. At the end of the experiment, highest TSS content ($26.9 \pm 0.57^\circ\text{B}$) was recorded in calcium hydroxide followed by sodium hydroxide treated fruits ($26.5 \pm 0.55^\circ\text{B}$) and the lowest value ($24.3 \pm 0.35^\circ\text{B}$) was recorded in control fruits. Titratable acidity (TA) was found decreased with the increase in storage period (Table 2). Calcium hydroxide treated fruits were recorded much faster decline in TA content as compared to other treatments and control. At the end of the storage period, calcium hydroxide treated fruits contained lowest value (0.05 ± 0.016 %) of TA with nonsignificantly followed by control and sodium

Table 1 Effect of different desapping treatments on Hunter color values of peel of mango fruit during storage at ambient condition (30 ± 2 °C, 75–80 % RH)

Peel color	Treatments	Storage period (days)				
		0	3	6	9	12
L^*	T ₁	53.1±0.485 Aa	56.6±0.897 Bc	59.4±0.940 Cd	62.9±0.298 Da	64.2±0.353 Da
	T ₂	53.4±0.540 Aa	58.6±0.730 Bb	61.7±0.835 Cb	64.0±0.935 Da	64.4±0.848 Da
	T ₃	53.4±0.585 Aa	55.8±0.485 Bc	57.0±0.265 Bc	59.4±0.465 Cb	63.6±0.387 Da
	T ₄	52.6±0.540 Aa	55.3±0.995 Bc	56.0±0.870 Bc	58.6±0.453 Cb	63.1±0.549 Da
	T ₅	52.9±0.993 Aa	53.9±0.953 Aa	54.3±0.468 Aa	56.9±0.738 Bc	60.8±0.666 Cd
a^*	T ₁	-12.5±0.335 Aa	-7.5±0.513 Ba	-4.1±0.439 Db	-1.9±0.416 Ea	0.53±0.386 Fc
	T ₂	-12.7±0.548 Aa	-6.8±0.135 Ba	-3.7±0.488 Db	-1.5±0.424 Ea	0.93±0.166 Fc
	T ₃	-12.9±0.555 Aa	-8.6±0.490 Cb	-6.8±0.408 Ba	-3.9±0.538 Db	-1.7±0.507 Ea
	T ₄	-12.2±0.568 Aa	-8.7±0.445 Cb	-7.2±0.500 Ba	-4.1±0.830 Db	-2.8±0.652 Db
	T ₅	-12.6±0.985 Aa	-9.3±0.410 Cc	-7.7±0.313 Ba	-5.4±0.608 Db	-3.3±0.199 Db
b^*	T ₁	18.2±0.745 Aa	25.4±0.783 Ba	30.9±0.366 Cc	33.7±0.551 Cd	35.43±0.536 Cd
	T ₂	18.4±0.383 Aa	27.1±0.925 Ba	33.1±0.983 Cd	34.8±0.760 Cd	36.02±0.548 Cd
	T ₃	18.6±0.693 Aa	23.4±0.465 Bb	25.8±0.753 Ba	32.4±0.448 Ca	34.52±0.452 Cd
	T ₄	18.6±0.463 Aa	22.6±0.675 Bb	25.1±0.485 Ba	30.9±0.745 Cc	33.61±0.450 Cd
	T ₅	18.3±0.458 Aa	20.9±0.590 Bb	24.0±0.940 Bb	30.1±0.563 Cc	32.76±0.800 Ca

According to HSD Tukey's test, treatment values with similar capital letters are not significantly different ($p<0.05$) during storage. For each sampling date, values with similar small letters are not significantly different ($p<0.05$) among treatments. Data are means±Standard error of three replicate determination ($n=3$).

T₁ Control, T₂ Calcium hydroxide (1 %), T₃ Sodium hydroxide (1 %), T₄ Alum (0.5 %), T₅ Alum (1 %)

hydroxide (0.08 ± 0.016 %) treated fruits. However, there was no significant difference in TA content among alum (0.5 and 1 %) treated fruits. Total sugars content also increased with the advancement of storage period (Table 2). Fruits

Table 2 Effect of different desapping treatments on total soluble solids (TSS), titratable acidity (TA) and total sugars of mango fruit during storage at ambient condition (30 ± 2 °C, 75–80 % RH)

Parameters	Treatments	Storage period (days)				
		0	3	6	9	12
TSS (°B)	T ₁	11.6±0.30 Aa	16.0±0.52 Bb	20.9±0.46 Ca	24.1±0.55 Da	24.3±0.35 Db
	T ₂	11.6±0.25 Aa	16.7±0.41 Bb	22.1±0.43 Cc	25.2±0.43 Db	26.9±0.57 Ea
	T ₃	11.4±0.55 Aa	15.6±0.35 Bb	20.3±0.40 Ca	24.1±0.38 Da	26.5±0.55 Ea
	T ₄	11.3±0.30 Aa	15.3±0.38 Bb	19.6±0.30 Ca	23.0±0.38 Da	25.3±0.45 Eb
	T ₅	11.1±0.60 Aa	15.1±0.32 Bb	18.1±0.35 Cd	22.0±0.45 Dd	24.8±0.30 Eb
TA (%)	T ₁	0.56±0.016 Aa	0.42±0.032 Ba	0.27±0.016 Ca	0.19±0.032 Da	0.08±0.032 Ea
	T ₂	0.54±0.032 Aa	0.40±0.016 Ba	0.26±0.032 Ca	0.14±0.016 Db	0.05±0.016 Ea
	T ₃	0.56±0.016 Aa	0.43±0.016 Ba	0.29±0.032 Ca	0.18±0.048 Da	0.08±0.016 Ea
	T ₄	0.54±0.032 Aa	0.43±0.016 Ba	0.32±0.016 Cb	0.19±0.032 Da	0.13±0.032 Ec
Total sugars (%)	T ₁	10.5±0.430 Aa	15.0±0.390 Ba	19.8±0.155 Ca	23.1±0.413 Da	24.0±0.281 Eb
	T ₂	10.2±0.376 Aa	15.6±0.408 Ba	21.2±0.323 Cb	24.6±0.323 Db	26.1±0.471 Ea
	T ₃	10.1±0.231 Aa	14.7±0.263 Ba	19.6±0.200 Ca	23.1±0.360 Da	25.7±0.174 Ea
	T ₄	10.1±0.291 Aa	14.3±0.285 Ba	18.5±0.225 Cc	22.1±0.285 Dc	24.3±0.263 Eb
	T ₅	9.8±0.349 Aa	14.0±0.240 Bb	17.1±0.259 Cd	21.1±0.334 Dd	23.8±0.275 Eb

According to HSD Tukey's test, treatment values with similar capital letters are not significantly different ($p<0.05$) during storage. For each sampling date, values with similar small letters are not significantly different ($p<0.05$) among treatments. Data are means±Standard error of three replicate determination ($n=3$).

T₁ Control, T₂ Calcium hydroxide (1 %), T₃ Sodium hydroxide (1 %), T₄ Alum (0.5 %), T₅ Alum (1 %)

treated with calcium hydroxide showed faster increase in total sugars, compared to other treatments and control while, slowest increase was recorded in alum (1 %) treated fruits. Among different treatments, fruits treated with calcium hydroxide showed highest (26.1 ± 0.471 %) total sugars content followed by sodium hydroxide (25.7 ± 0.174 %) while the lowest value (23.8 ± 0.275 %) was recorded in alum (1 %) treated fruits.

Fruit quality parameters like peel color, TSS, acidity and total sugars content were also significantly affected by different treatments used for desapping. Untreated and calcium hydroxide treated mango fruits showed much faster development of yellow color, which was attributed to faster ripening process, due to higher respiration and ethylene evolution rate. Thus, destruction of chlorophyll and synthesis of carotenoids was faster in these fruits. As a result of this, TSS and sugars content increased and TA content decreased rapidly in control and calcium hydroxide treated fruits. On the other hand, sodium hydroxide and alum treatment delayed the fruit ripening process by slowing down respiration and ethylene evolution rates, which depicts the reason for slower increase in TSS and total sugars content. This finding is in accordance with Maqbool and Malik (2008). However, after 9th day of storage, declining trend of TSS and total sugars content were found in control and calcium hydroxide treated fruits which might be attributed to utilization of substrate by disease causing microorganisms and higher respiration rate.

Conclusions

Sapburn injury, a major problem to external fruit quality of mango can be effectively reduced to a great extent by exogenous application of sodium hydroxide (1 %) just after harvesting. Apart from protection against sapburn injury, sodium hydroxide treatment also maintained desirable postharvest fruit quality traits like higher firmness, antioxidant capacity, phenolics, total carotenoids content; lower physiological loss in weight and enzymatic activity. The shelf-life of fruit was also extended with this treatment by lowering respiration, ethylene evolution rate and thus delaying the ripening process.

References

- Abu-Sarra AF, Abu-Goukh AA (1992) Changes in pectinesterase, polygalacturonase and cellulase activity during mango fruit ripening. *J Hort Sci* 67:561–568
- Ali ZM, Chin LH, Lazan H (2004) A comparative study on wall degrading enzymes, pectin modifications and softening during ripening of selected tropical fruits. *Plant Sci* 167:317–327
- Amin M, Malik AU, Mazhar MS, Din I, Khalid MS, Ahmad S (2008) Mango fruit desapping in relation to time of harvesting. *Pak J Bot* 40:1587–1593
- AOAC (2000) Official Methods of Analysis, 17th edn. Association of Official Analytical Chemists, Gaithersburg
- Apak R, Guclu K, Ozyurek M, Karademir SE (2004) Novel total antioxidant capacity index for dietary polyphenol and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine, CUPRAC method. *J Agric Food Chem* 52:7970–7981
- Baker I (1991) Mango Quality Program, 1990. Final Report for N.T. Horticultural Association, Mimeograph
- Barman K, Asrey R, Pal RK (2011a) Overcoming sapburn injury in mango. *Indian Hort* 56:14–16
- Barman K, Asrey R, Pal RK (2011b) Putrescine and carnauba wax pretreatments alleviate chilling injury, enhance shelf life and preserve pomegranate fruit quality during cold storage. *Sci Hort* 130:795–800
- Barman K, Asrey R, Pal RK, Kaur C, Jha SK (2011c) Influence of putrescine and carnauba wax on functional and sensory quality of pomegranate (*Punica granatum* L.) fruits during storage. *J Food Sci Technol*. doi:10.1007/s13197-011-0483-0.
- Bosquez E, Figueroa SC, Dominguez J, Perez L, Kerbel C, Diaz-de-Leon F (2000) Sapburn control by the application of different chemical compounds in Mexican mango fruit with exportation quality. *Int Symp Mango*, Pattaya
- Briante R, Patumi M, Limongelli S, Febbraio F, Vaccaro C, Salle AD, Cara FL, Nucci R (2002) Changes in phenolic and enzymatic activities content during fruit ripening in two Italian cultivars of *Olea europaea* L. *Plant Sci* 162:791–798
- Campbell J (1992) A Guide to Mangoes in Florida. Miami, Fairchild Tropical Garden, p 227
- Elyatem SM, Kader A (1984) Post harvest physiology and storage behavior of pomegranate fruits. *Sci Hort* 24:287–298
- Fallahi E (1997) The role of calcium and nitrogen in postharvest quality and disease resistance of apples. *HortSci* 32:831–835
- Hagerman AE, Austin PJ (1986) Continuous spectrophotometry assay for plant pectin methyl esterase. *J agric Food Chem* 34:440–444
- Joel MD (1980) Resin ducts in the mango fruit: A defense system. *J Exp Bot* 31:1707–1718
- John KS, Bhat SG, Rao UJSP (2003) Biochemical characterization of sap (latex) of a few Indian mango varieties. *Phytochem* 62:13–19
- Kulkarni AP, Aradhya SM, Divakar S (2004) Isolation and identification of a radical scavenging antioxidant- punicalagin from pith and carpellary membrane of pomegranate fruit. *Food Chem* 87:551–557
- Landrigan M, Morris S, Baker I, Cole S, Kuppelweiser W (1991) Postharvest studies with mangoes. *Tech Annu Rep* 1989–90:93–97, Horticulture Branch, Department of Primary Industry and Fisheries, N.T. Technology, Bull No. 175
- Lazan H, Ali ZM, Liang KS, Yee KL (1989) Polygalactouronase activity and variation in ripening of papaya fruit with tissue depth and heat treatment. *Physiol Plant* 77:93–98
- Ledger SN (1991) Effectiveness of detergents in reducing mango sapburn 1990/1991 season. Postharvest Report, Queensland Department of Primary Industries, Queensland
- Lim TK, Kuppelweiser W (1993) Mango sap burn amelioration in the Northern Territory. *Acta Hort* 341:518–527
- Loveys BR, Robinson SP, Brophy JJ, Chacko EK (1992) Mango Sapburn: Components of fruit sap and their role in causing skin damage. *Aust J Plant Physiol* 19:449–457
- Madrid R, Valverde M, Alcolea V, Romojaro F (2004) Influence of calcium nutrition on water soaking disorder during ripening of Cantaloupe melon. *Sci Hort* 101:69–79
- Maqbool M, Malik AU (2008) Anti-sap chemicals reduce sapburn injury and improve fruit quality in commercial mango cultivars of Pakistan. *Int J Agri Biol* 10:1–8

- Maqbool M, Malik AU, Jabbar A (2007) Sap dynamics and its management in commercial mango cultivars of Pakistan. *Pak J Bot* 39:1565–1574
- Menezes JB, Alves RE, Freire FCO (1995) Mango sapburn- a postharvest injury. *R Bras Fisiol Veg* 7:181–184
- Meurant N (1991) Bowen Mango Field Day. *Mango Care Newsletter*, vol 3. Queensland Department of Primary Industries, Queensland
- Mortuza GM, Hag LL (1996) Control of banana fruit rots by alum. *Musarama* 32:70–71
- O'Hare T, Prasad A (1991) The alleviation of sap induced mango skin injury by calcium hydroxide. *Int. Symp. Tropical Fruits, Pattaya*
- Roy SK (1973) A simple and rapid method for estimation of total carotenoid pigments in mango. *J Food Sci Technol* 10:38–42
- Singleton VL, Ross JA (1965) Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Amer J Enol Vitic* 16:144–158
- Valero D, Romero DM, Serrano M, Riquelme F (1998) Influence of postharvest treatment with putrescine and calcium on endogenous polyamines, firmness, and abscisic acid in Lemon (*Citrus lemon* L. Burm cv. Verna). *J Agric Food Chem* 46:2102–2109