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Postharvest high Carbon Dioxide and Hot Water Treatments for Maintaining Quality of Ewase Mango Fruits

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Abstract: Postharvest quality of Ewase mangoes (*Mangifera indica* L) is vital to ensure proper ripening and good quality. The effect of postharvest applications of modified atmosphere and hot water treatments were applied to Ewase mango fruits at the two seasons of 2012 and 2013. Mature Ewase fruits were subjected to modified atmosphere (MA) at 2% or 7% CO_2. Other mangoes were also subjected to hot water dipping (HWD) at 48 or 52ºC for 10 min. All treated and control fruits were stored at 10ºC with 85-90% relative humidity for 4 weeks. Responses of fruit quality characteristics as physical and chemical properties to MA and HWD throughout storage period were studied. Fruit quality characteristics i.e. weight losses, decay percentage, CO_2 production (respiration rate), skin color (hue angle), fruit firmness, total soluble solids content (TSS), titratable acidity (TA), and ascorbic acid (VC) content, were evaluated periodically after 7 days of storage for 4 weeks. Among different treatments, weight loss percentage was lower in fruit treated with HWD treatments than untreated ones (4.09%). Meanwhile, there were inversely relation between CO_2 concentrations and mango fruit weight loss percentage. All treatments (MA and HWD) did not have any discarded fruits until two weeks of storage period, while control fruits exhibited the highest percent of decay (33%). Treated fruits with high carbon dioxide 7% gave the least CO_2 production (25 mgkg^{-1}hr^{-1}) with the same pattern after hot water dipping. The highest value of CO_2 production (33.5 mg kg^{-1}hr^{-1}) recorded by HWT at 48°C compared control fruits (37 mg kg^{-1} hr^{-1}). Ewase Mango peel color change from green to yellow progressed rapidly in untreated fruits from the initial time (114.80) to (74.14) at the end of storage at 10ºC for 4 weeks. HWD treatments showed maximum color value (84.13) at 52°C followed by (82.21) at 48^{o}C for 10 min. The highest hue angle values (93.10 and 89.12) in MA treatments recorded by 7% CO_2 and 2% CO_2 respectively. Treated fruits with CO_2 at 7% gave the highest firmer fruit (11.87) followed by CO_2 at 2% (11.70) compared with untreated fruit (8.70). A similar decline in fruit firmness was found in mangoes stored at 10^{o}C after dipping in hot water (HWD) at 48 and 52^{o}C for 10 min with less value Fruits treated with MA concentrations gave the highest SSC and VC content with lower titratable acidity. Meanwhile, HWD applications had less TSS and VC content with higher TA percent in both conditions throughout storage period.

Keywords: Ewase mango, Modified atmosphere, Carbon dioxide, Hot water, Fruit quality.

Introduction

Mango (*Mangifera indica* L.) belonging to the Anacardiaceae family, is one of the oldest and most important tropical fruit having heavy demand in world market due to its bright color, characteristic taste, and nutritional value. Mango fruits destined for export are commonly required to have thermal treatments against invasive pests, to prolong shelf life and preserve fruit quality to fulfill the consumers and markets demand[1]. Its climacteric and generally highly perishable[2] ripen rapidly after harvest. Disease susceptibility, sensitivity to low storage temperatures (below13°C), and perishability due to ripening and softening, limit the storage, handling and transport potential of the fruit[3].

Mangoes destined for import may be infested with various species of fruit flies, so that fruit must be subjected to a thermal quarantine treatment involving complete hot water immersion for a specified time and temperature reported by [4.] Among different heat treatments, use of hot water as a disinfestations treatment, has been widely adopted because of its efficiency added by [4, 5]. However, the effects of hot water treatment may prove to be an effective to maintain fruit quality and inhibit ripening prior to distribution. Previous studies on HWT show that the effects depend upon a number of factors including maturity stage, cultivar, HWT temperature and duration etc. [6]. The use of heat treatments applied by hot water has increased in order to control insect pests, prevent fungal rots and increase resistance to chilling injury [3,7]. Heat treatments also inhibited ripening, softening and improved postharvest quality.

Hot water immersion has a number of advantages, which include short treatment time. An increase in ethylene production as a response to heat stress measured by [8]. Increases in ethylene production might stimulate ripening processes. However, this stimulus could be limited because of the effects of elevated temperatures on the enzymes of the ethylene biosynthetic pathway [9]. Hot water has earned firm and adoption at a large scale because of the high efficacy in reducing the postharvest disease as well as the low cost[10].

The modified atmosphere affects physicochemical and physiological processes in fruits positive or negative effects[11]. Controlled atmosphere (CA) storage is used to maintain mango fruit quality, slow fungal decay development, and to extend postharvest life during transportation and storage [12, 13]. Although, some earlier researchers have employed low/ high CO_2 treatments to increase shelf life and quality of mangoes , utilize controlled atmosphere or low carbon dioxide or when used high carbon dioxide in modified atmosphere , it is used for very short time span before storage conditions are set, whereas our study aims to look at the net effect of high CO_2 concentrations under modified atmosphere along with film properties and different hot water dipping temperatures to improve the shelf life of mangoes stored at 10°C [14-18,4].

Low O_2 concentrations generally reduce respiration and ethylene production rates; high CO_2 concentrations also hinder ripening, possibly, because CO_2 acts as a competitive ethylene inhibitor[19]. Many fruits tolerate a minimum 2% O_2 concentration; lower O_2 levels induce anaerobic respiration, which could result in the development of undesirable off-flavors and odors due to the accumulation of ethanol, acetaldehyde and other volatiles in these conditions[20]. Tolerance limits to elevated CO_2 concentrations vary widely between fruit species; some fruit tolerate CO_2 concentrations higher than 5%, whereas others develop disorders at this CO_2 level [19]. Tolerance to elevated CO_2 decreases with reduced O_2 level and, similarly, tolerance limits to low O_2 concentration increase with increased CO_2 level[20].

The aim of this paper, therefore, was to study the effects of postharvest high carbon dioxide and hot water treatments for keeping quality of Ewase mango fruits.

Materials and Methods

Fruits:

Mature green mango fruits (*Mangifera indica* L.) of the Ewase cultivar were collected from a private orchard (Nemous) El Katta district, Giza Governorate**.** Mango fruits were carefully handpicked from trees at the first of September of 2012 and 2013from trees were 15 years old, grown in sand-loam soil, were similar in growth and received common horticulture practices. Uniformly sized fruits without any defects were selected for this experiments and transported carefully to the laboratory of Agricultural Development Systems (ADS), Faculty of Agriculture, Cairo University.

On arrival, undamaged fruits free from apparent pathogen infection and similar in shape, color, and firmness were selected, washed, in chlorinated water (100 ppm free chlorine) for 10 min., air dried and randomly distributed for hot water and modified atmosphere treatments. The initial quality measurements were determined.

Treatments:

A- Hot Water Dipping (HWD):

Ewase mango fruits (15 and 30 fruits/treatment) were dipped in hot water bath at 48 and 52°C and the HWD durations were performed for 10 minutes. The pulp temperatures were taken for initial and last of the trial. Following treatments, fruits were placed into cold water for 10 min. too and allowed to air dry. Control fruit were treated only with tap water. After treatments, all treated and non – treated fruits were packed in corrugated cardboard boxes and then stored at 10°C in controlled temperature rooms with 85-90% relative humidity for 4 weeks. Each treatment constituted three replications for each sampling date (7 days) and each replicate consisted of 5 fruits through storage period (4 weeks).

B- Modified Atmosphere (MA):

Fruits were enclosed in 10–L glass jars for modified atmosphere treatments. Nitrogen from nitrogen cylinder was flushed into the jars for complete replacing N instead of normal air. The jars were connected with Servmex instrument (Food Pack Gas Analyzer Model 1450C). Oxygen and carbon dioxide concentrations were flushed from O_2 and CO_2 cylinders to the jars and fruits were subjected to two MA conditions of 2% O_2 plus 2 or 7% CO_2. The balance of all treatments was N_2. The control fruits were placed in jars with aerobic atmosphere. After treatments, all fruits (jars) were closed and stored at 10°C and 85 – 90 % RH. Three replicates for each treatment and sampling time were used and each replicate consists of 5 fruits for Ewase mango fruits. Samples for fruit quality assessment were taken at 7 days intervals through storage period (4 weeks).

C- Gases measurements and Fruit quality were determined as follows:

Weight loss: weight loss percentage was calculated during storage as the following equation:

$$\text{Weight Loss \%} = \frac{A-B \times 100}{A}$$

Where:

A = the initial weight at the beginning of storage

B = weight at inspect date as mentioned in [21].

Decay percentage:

Fruits, which were decayed by different physiological and pathological factors, were periodically counted and discarded. Then percentages of decayed fruits were calculated in relation to total number of fruits.

CO_2 production (respiration rate):

Fruits of each sampling date were weighed and placed in 2-liter sealed jars at 10°C. O_2 and CO_2 production samples of the jars headspace were injected into Servomex Inst. (Model 1450C-Gas Analyzer). Respiration rate was calculated as ml CO_2/kg/hr[22, 23].

Skin Color (Hue angle):

Color was measured by using Minolta colorimeter (Minolta, 300, Osaka, Japan) for measuring the values of a*, b* and hue angle (h◦). In this system of color representation the values of a*, b* and hue angle (h◦) describe a two-dimensional color space, where values of a* and b* specify the green-red and blue-yellow axis, respectively. Hue (h◦) determines the position of such vector. H° values were calculated based on a* and b* values according to the following equations:

$h^\circ = \tan^{-1}(b^*/a^*)$.

Five fruits were measured objectively by averaging three measurements taken around the fruit equator, on the external tissue (skin fruit). Color was longitudinally determined on three points of each fruit [24].

Fruit firmness:

Fruit firmness was measured using Ametek pressure tester, fitted with an 8 mm hemispherical probe (probe penetration 2 mm). Firmness of five fruits from each replicate was measured at two opposite points on the equator of each fruit. The results are calculated as described at [25].

Fruit quality analysis:

TSS content was measured using a T/C hand refractometer. **Total Acidity (TA)** expressed as malic acid was determined by titrating 5 ml juice with 0.1N sodium hydroxide using phenolphthalein as an indicator. **Ascorbic acid content (VC)** was measured using 2, 6 dichlorophenol indophenols' method described by[26].

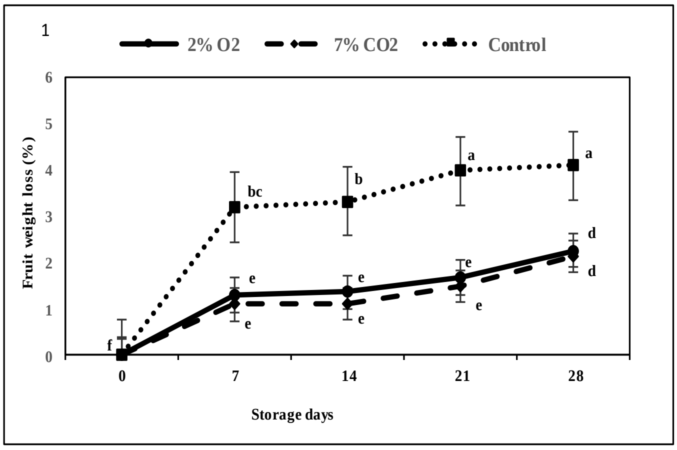
Statistical analysis:

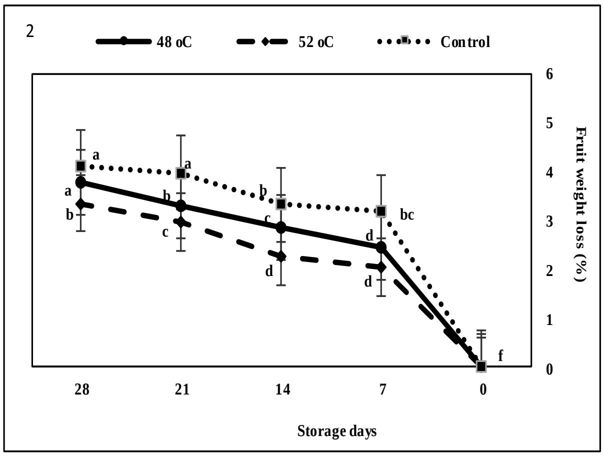
The design for this experiment was a completely randomized design (CRD) with three replications. Data were analyzed with the analysis of variance (ANOVA) procedure of MSTATC program. When significant differences ($P>0.05$) were detected, data was treated by analysis of variance with standard deviation[27]. Data was treated by analysis of variance with standard error.

Results and Discussion

Weight loss percentage:

Fruit weight loss was directly proportional to the length of storage period. As shown in Figs (1and 2), a gradual increase in the cumulative weight loss percentage in the 'Ewase' mango fruit throughout postharvest storage either with hot water dipping (HWD) or with modified atmosphere (MA) treatments towards the end of storage period (4 weeks). In General, all treated fruits recorded lower significant weight loss percentage than untreated ones which having the higher percent (4.09%) at the end of storage period. Meanwhile, the results obtained from the statistical analysis of Ewase mango fruits treated with hot water at 48°Cshowed rapid increase in weight loss percent in comparison to treatment at 52°C (3.97 and 2.49% respectively). On the other hand, there were inversely relation between CO_2 concentrations and mango fruit weight loss percentage. The least weight loss percentage (2.13%) was recorded due to MA treatment of 7% CO_2 at 10°C for 28 days. Our results are further in line with[28] in avocado fruits, that mass losses were 4.3% at 20°C for 8 days and 3.0% at 10°C for 22 days. A significant effect of storage ($P<0.05$) on Dusheri variety of mango was observed and had an increasing trend of average percent weight loss. Regarding the effect of storage temperatures on the changes in fruit weight loss of Keitt and Nam Doc Mai mango fruits, the data of both varieties indicated less weight loss in 7°C and high weight loss in room temperature of 25°C, leading to significance difference in fruits weight loss between the two temperatures[29].

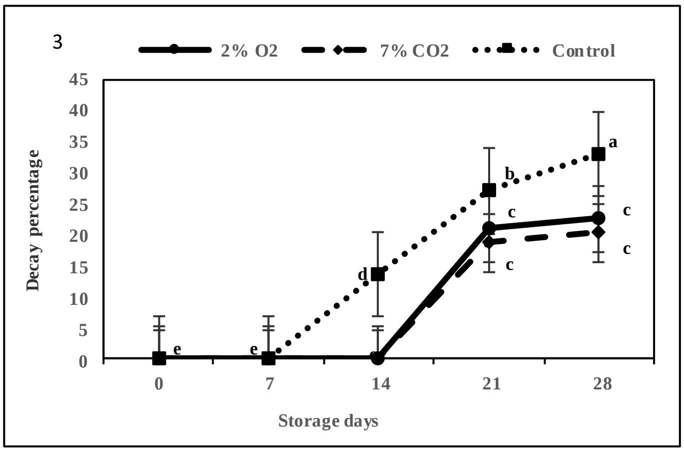


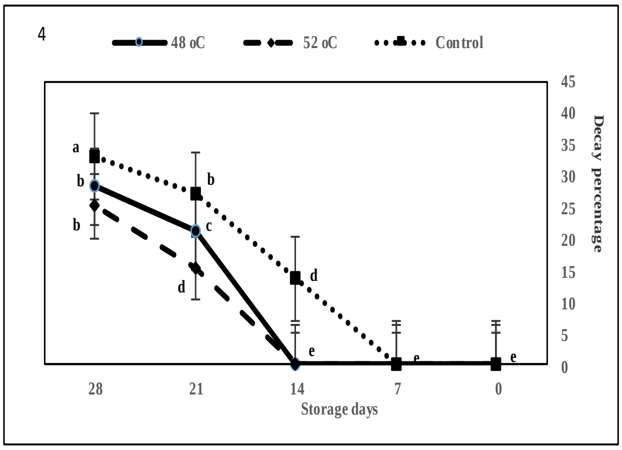


Figs. 1 and 2: Weight loss percentage of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E**.**

Decay percentage:

The present results in Figs (3 and 4) indicated that not all treatments (modified atmosphere and hot water) had any discarded fruits until two weeks of storage period. Thereafter, decay percentage showed significant and gradual increase with the progress of storage period. At the 4*th* week of storage, the untreated fruits (control) exhibited the highest percent of decay (33**)**. Meanwhile, the incidence of decay in treated fruits with 7% CO_2, reached the least percent (21.25) followed by 2% CO_2 treatment (22.49). On the other hand, the same pattern was observed after dipping fruit in hot water treatments, the least value of decay incidence recorded by HWT at 52°C (25.26) followed by HWT at 48°C (24.14) compared with untreated (control) fruit. These results are in harmony with [30] who reported that avocado fruit stored at 5°C caused lower chilling injury compared with 1.1 °C. Moreover, storage at 8°C for one week resulting in more intense vascular browning at full ripening upon transfer to 22°C. Treating Kensington mango with HWT at 53°C for 5 min lowered disease incidence, while severity of fruit injury was lower in HW + VHT fruits than in VHT fruit alone found by [31]. The hot water immersion treatment was effective in decreasing the severity of many common physiological postharvest disease-affecting mango[4].

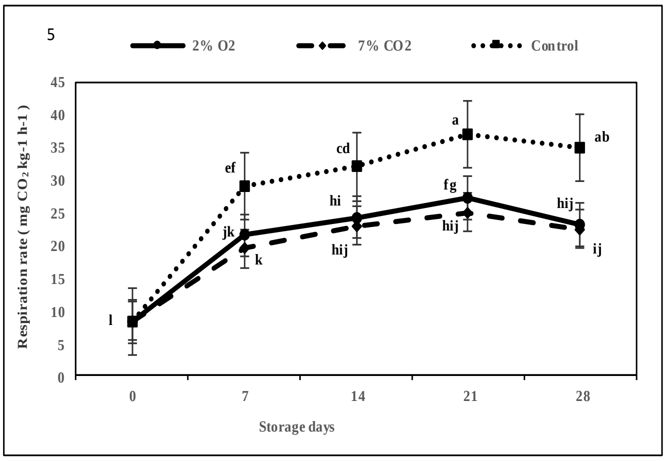


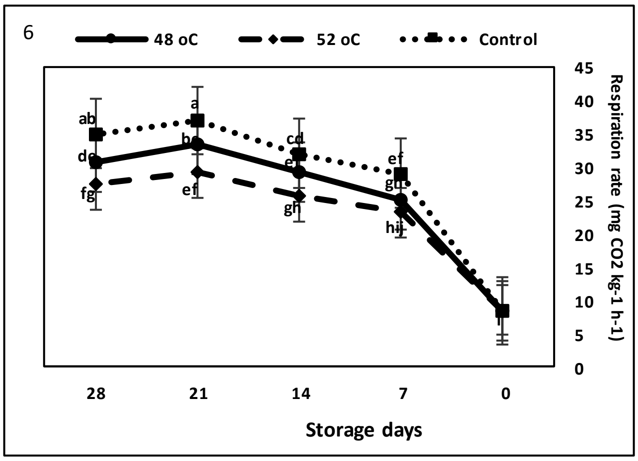


Figs. 3 and 4: Decay percentage of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4*th* week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E**.**

CO_2 Production (respiration rate /mg kg^{-1} hr^{-1}):

The respiration rate is an indicator of metabolic activity and gives an indication of the potential shelf life of the product [32]. The present results in Figs (5 and 6) indicated that all postharvest treatments (modified atmosphere and hot water) showed significant and gradual increase in CO_2 production with the progress of storage period up to 3 weeks then decreased. Treated fruits with high carbon dioxide 7% gave the lowest CO_2 production (25) followed by CO_2 2% (27.30). On the other hand, the same pattern was observed after dipping fruit in hot water treatments, the least value of CO_2 production recorded by HWT at 52°C (29.15) followed by HWT at 48°C (33.5) compared with untreated fruit (control) which recorded the highest respiration rate (37 mg kg^{-1} hr^{-1}). The RR values of 'Irwin' mango treated with HWD 47.2 ◦C/60, 90 and 120 min. ranged between 0.92 and 1.05 and were not affected by heat treatment[33]. HWD 50°C/30min. could increase the shelf life of fresh-cut mangoes by decreasing respiration rate of whole mangoes[6]. Modified atmosphere condition 5% O_2+8%CO_2 resulted in great reduction in respiration rate of avocado fruits reported by [34].

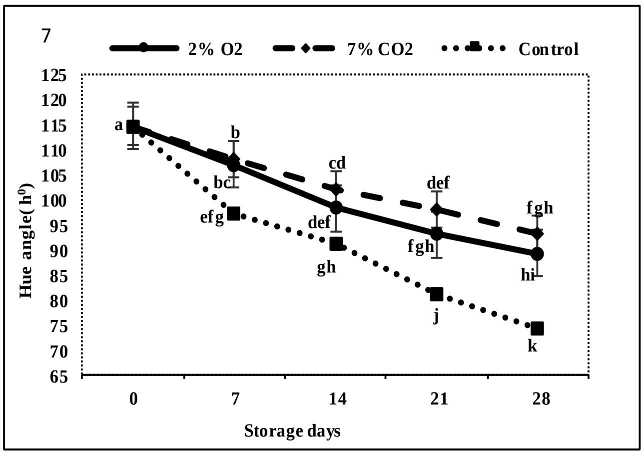


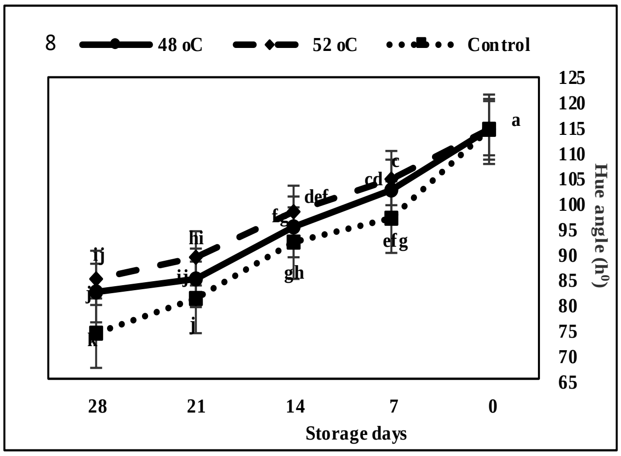


Figs. 5 and 6: CO_2 Production (mg kg^{-1} hr^{-1}) of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E.

Fruit Skin Color (hue angle):

The Hue angle was calculated and used for graphical depiction. Hue angle value, which is the angle from the +a axis to the ray from the origin to the a* and b* point, is a good estimate of the green to yellow color turn[24]. Results in Figs. (7 and 8) illustrated that hue angle as skin color parameter decreased gradually in all used treatments fruits with the advance in storage period.



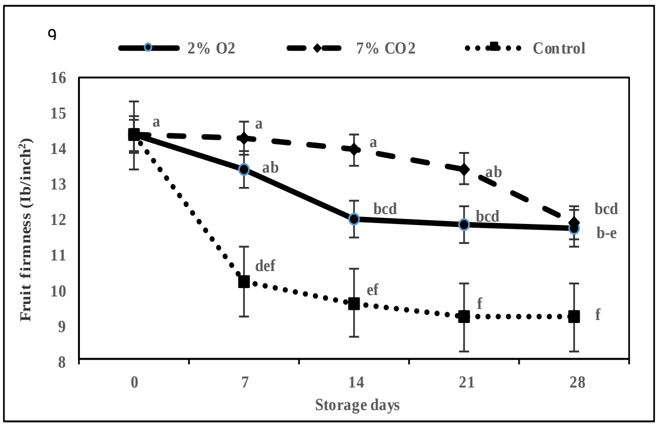


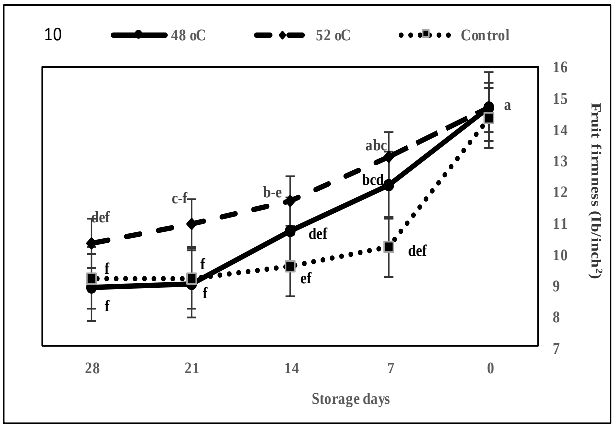
Figs. 7 and 8: Fruit skin color (h°) of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E

Ewase Mango peel color change from green to yellow progressed rapidly in untreated fruits (control) from the initial time (114.80) to (74.14) at the end of storage at 10ºC for 4 weeks. Hot water dipping treatments played a significant role ($P<0.05$), where in mangoes initially dipped in water maintained at 52°C for 10 min., showed maximum color change value (84.13) followed by (82.21) at 48°C for 10min., the values being means taken across and hot water dipping treatments. Modified atmosphere (MA) treatments exhibited significantly higher values than hot water applications of hue angle due to CO_2 concentration. The highest hue angle values (93.10 and 89.12) in MA treatments recorded by 7% CO_2 and 2% CO_2 respectively.These results also coincide with the earlier findings of [35] who concluded that HWT at higher temperature (52°C for 20 minutes) enhanced peel color when the fruit were ripened. Hue angle value which is the angle from the +a axis to the ray from the origin to the a* and b* point, is a good estimate of the green to yellow color turn [24] This is coherent to various previous data which reports that high temperature hot water dipping (40°C) is beneficial is maintaining uniform good ripening color as similar of the mango compared to the mangoes at the start of the experiment [15,6,36].

Fruit firmness (Ib inch^{-2}):

Fruit firmness is one of the criteria of fruit quality determined by various researchers for different fruits. After postharvest treatments (MA and HWD), the changes of fruit firmness of Ewase mango are presented in Figs. (9 and 10). At the beginning of storage (time zero), the firmness value were similar between treatments and then showed gradual and significant reductions during storage at 10°C for 28 days. Treated fruits with high carbon dioxide at 7% gave the highest firmer fruit (11.87) followed by CO_2 at 2% (11.70) compared with untreated fruit (8.70). A similar decline in fruit firmness was found in mangoes stored at 10°C after dipping in hot water (HWD) at 48 and 52°C for 10 min



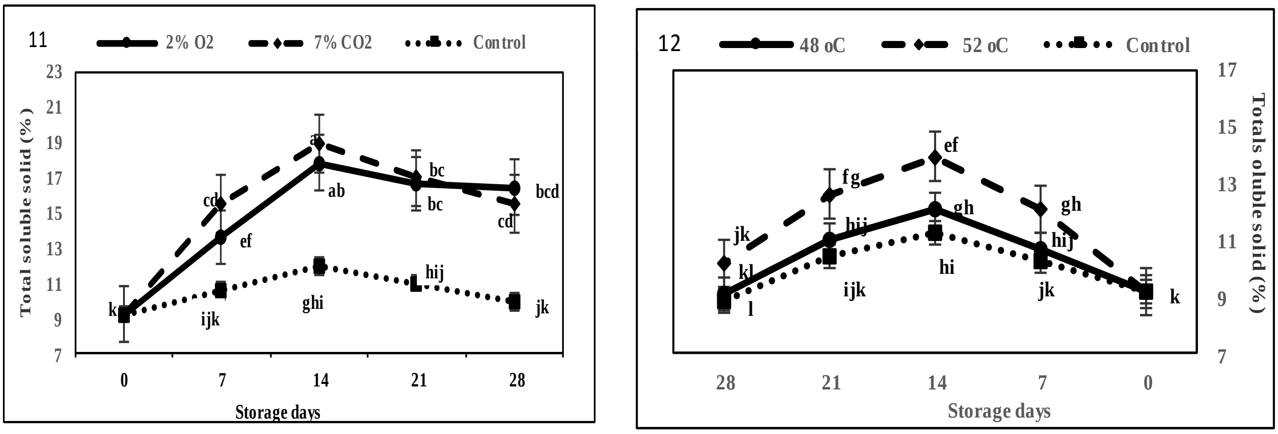


Figs. 9 and 10: Changes of mango fruit firmness (Ib inch^{-2}) affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E.

Meanwhile, Mangoes dipped in hot water at 52°C for 10 min showed firmer fruit firmness (10.30) followed by fruits dipped at 48°C (8.91) compared with control fruit (8.70). As reported by many authors, the differences in firmness of the mango fruits could be as a result of respiration which enhances ripening, water temperature and dipping time. Temperature of HWD treatments played a significant role ($P<0.001$) in maintaining firmness of the flesh. According to [37], inhibition of solubilisation of the carbonate-soluble pectin fraction is one of the main factors contributing to firmness retention due to heat treatment. Loss in fruit firmness was also high in temperatures of 25^{O}C compared to 7^{O}C in both varieties but Nam doc mai variety retained fruits firmness better than the Keitt fruits[29]. HWD at 40°C for 40 min maintained firmness of fresh Alphonso mangoes reported by[38]. CO_2 as a product of respiration inhibits the respiration of fruit. However, it would have negative effects on the dehydrogenase system if the CO_2 concentration was too high which would lead to a deterioration in the fruit quality [39].

Total soluble solids (TSS):

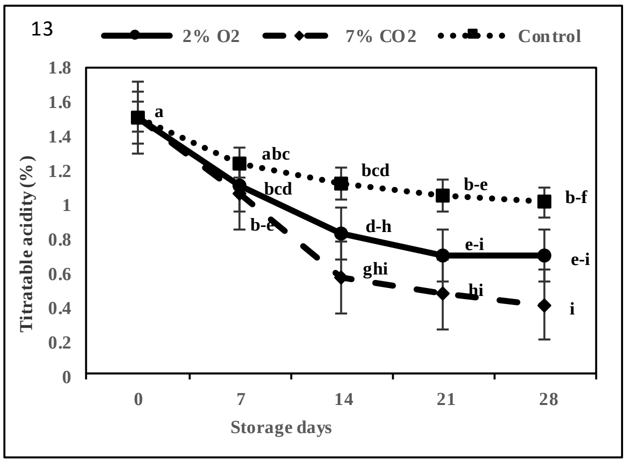
Total soluble solids content (TSS) in mango fruits cv. Ewase was affected significantly by both the modified atmosphere and hot water treatments. Meanwhile, modified atmosphere treatment had more effective on TSS content than hot water Figs. (11 and 12). Data revealed that significant increase in TSS content occurred with the progress of storage period up to 14 days and thereafter, a gradual decrease was observed up to the end of storage period. Fruits treated with high carbon dioxide 7 %CO_2 gave the highest SSC content (16.40) followed by 2 %CO_2 (15.50) in addition, Mangoes dipped in hot water at 52°C for 10 min recorded the highest SSC content (10.08) followed by fruits dipped at 48°C (10.13) compared with untreated fruit (control, 9.87). This increase and decrease in TSS are directly correlated with hydrolytic changes in starch and conversion of starch to sugar being an important index of ripening process in mango and other climacteric fruit and further hydrolysis decreased the TSS during storage[40,41]. Similar results were obtained by[42] who reported that conditioning (Kensington) at 40°C prior to HW treatments of 45°C for 30 min or 47°C for 15 min accelerated fruit ripening, increased Brix compared to untreated fruits and fruits receiving other heat treatments. Also, Djioua *et al.* [6] showed that the final TSS value was higher after 9 days of storage by hot water dipping for 50^{o}Cat 30 min. (Keitt cv).

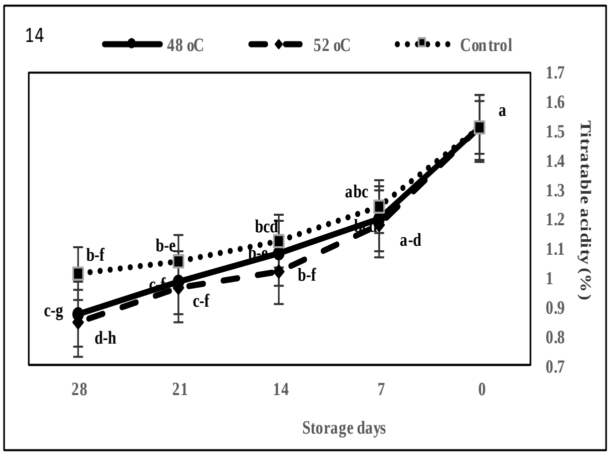


Figs.11 and 12: Total soluble solids (TSS %) of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E.

Titratable acidity (TA):

The changes in titratable acidity of Ewase mango fruits during storage at 10^{o}C subjected to modified atmosphere and hot water treatments are presented in Figs. (13 and 14).The results revealed that the percent of titratable acidity (TA) of treated Ewase mango decreased significantly and gradually until the end of storage period. Modified atmosphere treatments exhibited significantly lower titratable acidity content compared with hot water treatments. Moreover, control fruits showed the highest percentage of total acidity in the average of two seasons. The higher carbon dioxide 7% CO_2 led to higher rate of reduction in the titratable acidity, (0.41) followed by 2% CO_2 (0.7). Mango fruit treated with hot water dipping (HWD) recorded firmness values (0.84) at 52°Cand (0.84) at 48°C compared with untreated fruit, which recorded the lower rate of reduction (1.01) in the titratable acidity. Reduction in acidity may be due to their conversion into sugars and their further utilization in metabolic process in the fruit. These results are confirmed with those of [44] who reported that the major changes were considerably increased in pH from 2.85 to 4.38 and decreased in acidity from 2.71 to 0.04%during ripening in different varieties of mango fruit stored at 18-34^{o}C. The lowest acidity levels upon ripening in hot water dipped fruits, which were stored in cardboard boxes observed by[44]. Decreases in total acidity as mangoes ripen, as citric and malic acid are used as respiratory substrates according to[42].

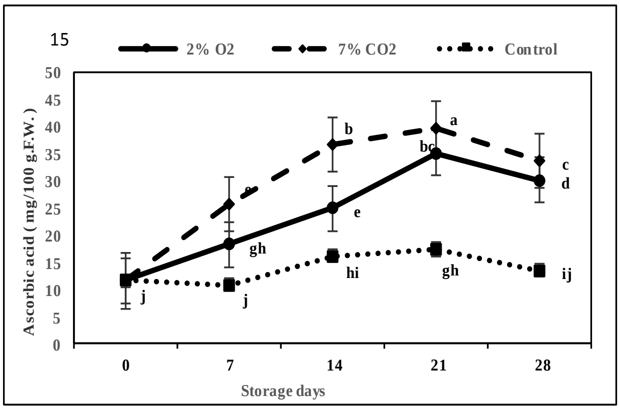


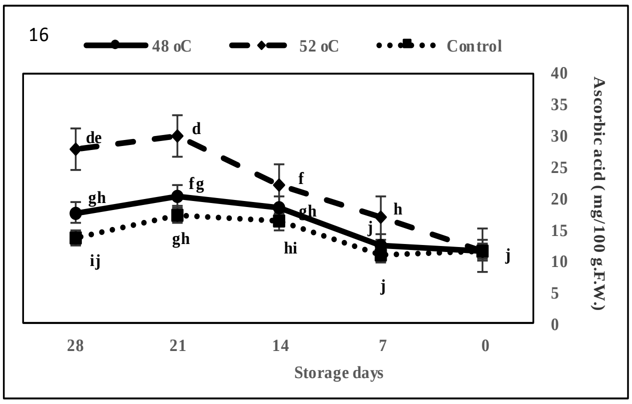


Figs.13 and 14: Titratable acidity (TA %) of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4*th* week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E.

Ascorbic acid content (VC):

Results of ascorbic acid content (VC) in Ewase mango fruits varied considerably, depending on modified atmosphere and hot water treatments Figs. (15 and 16). Generally, fruits treated with modified atmosphere conditions exhibited higher ascorbic acid concentrations than those treated with hot water compared with untreated ones. Mango fruits treated with the higher carbon dioxide 7% led to higher content (33.60) of ascorbic acid, followed by (30.10), in fruits treated with 2% CO_2. In addition, HWT produced fruits with less VC content (27.80 and 17.60) at 52°C and at 48°C respectively, compared with untreated (control) fruit which recorded the least content of ascorbic acid ranged from 11.50 at harvest to 13.47 mg/100g F.W. after 4*th* week of storage period. HWD at 40°C for 40 min maintained vitamin C content of fresh Alphonso mangoes[38]. Ascorbic acid levels were higher in mangoes dipped in hot water (50°C/30 min) at the end of 9 days. However, with a proper time–temperature combination, like HWD 40°C/40 min, this decree se can be reduced and fresh-cut products can still contain significant amounts of vitamin C after storage for 21 days reported by[6].





Figs.15 and 16: Ascorbic acid content (mg/100g F.W.) of mango fruit affected by modified atmosphere (MA) and hot water dipping (HWD) treatments for 4th week of storage period (average of 2012 and 2013 seasons). The vertical bars represent a mean of ±S.E

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