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INFLUENCE OF 1-METHYLCYCLOPROPENE ON POSTHARVEST STORAGE OF PAKISTANI MANGO (*Mangifera indica* L.) VARIETIES AT DIFFERENT HARVEST MATURITY

Sidrah[1,*], Muhammad Atif Randhawa[1], Naveed Ahmad[1] and Muhammad Shahid[2]

[1]National Institute of Food Science and Technology, University of Agriculture, Faisalabad- 38040, Pakistan;
[2]Department of Biochemistry, University of Agriculture, Faisalabad 38040, Pakistan
[*]Corresponding author's e-mail: sidrah.rafique@yahoo.com

Harvest maturity was specified for 'Langra', 'Dusehri' and 'S.B. Chaunsa' mango varieties with 1-methylcyclopropene (1-MCP) application for preserving maximum postharvest quality of mango during low temperature storage (30 days). 1-MCP was applied at 0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$ concentration. Ripening indices were observed of each variety at every 10^{th} day for mature green (M1) and sprung (M2) maturity stages. Total soluble solids (TSS) and titratable acidity (TA) decreased with the passage of time, while 1-MCP treated fruit retained higher TSS and TA during storage. Rate of respiration (mmoles $CO_2 \cdot kg^{-1} \cdot h^{-1}$) increased gradually till climacteric rise occurred but less peak height was observed at M1 under 1-MCP application. Physiological weight loss (%) of 1-MCP treated fruit reduced, resultantly less wilting and skin shriveling was observed at M1. Peel color changes in control treatment was rapid (yellow color with black spots) with increased ripening index at M2 stage. Peel color of 'Langra' mango remained green among treatments, while fruit of 'Dusehri' and 'S.B. Chaunsa'when subjected to 1-MCP showed least color score (51 to 75 % yellowing) at M1 and M2, respectively. 1-MCP delayed ripening of mango fruit at low to moderately high concentration depending upon the fruit variety for 15 (M2) to 20 days (M1). 'Langra' mango showed best response to 500 while 'Dusehri' and 'S.B. Chaunsa' varieties at 1000 $nL \cdot L^{-1}$ concentration of 1-MCP. It can be concluded that 1-MCP in combination with other postharvest strategies found effective in maintaining good keeping quality of mango when fruit harvested at mature green stage (M1).
Keywords: 1-methylcyclopropene, respiration, climacteric peak, ripening rate, maturity indices.

INTRODUCTION

Mango (*Mangifera indica* L.) is one of the delicious fruit rich in vitamins, minerals and nutritious attributes and frequently grown in tropical and sub-tropical regions of the world including subcontinent (Rodriguez-Casado, 2014). Fruit have been characterized into climacteric and non-climacteric nature based on their ripening pattern (Kader, 2004). Mango called 'King of Fruit' comes under the category of climacteric fruit. Climacteric fruit ripen with burst of ethylene release and higher respiration resulting, number of metabolic changes in fruit such as de-greening (yellow color development), gluconeogenesis (starch degradation into sugars), development of aromatic compounds, taste and fruit softening (Brecht and Yahia, 2009; Payasi *et al*., 2009; Singh *et al*., 2013; Razzaq *et al*., 2015).

Pakistani mangoes are internationally famous due to their unique taste and flavor (Rathore *et al*., 2007; Hussain *et al*., 2015; Ahmed *et al*., 2020). Export volume of Pakistani mangos reaches upto 80,000 metric tons which is $50 million (Abbas, 2020), that covers only 4% to 5% of yearly production owing to poor postharvest handling of mango fruit resulting reduced shelf life of mango. Postharvest life and quality parameters of fruit strongly dependent upon stage of harvesting. Mangoes are harvested at different ripening stages viz., physiologically mature but hard green, $1/4^{th}$ ripened (sprung), half-ripened and fully ripened stage. Usually, mangoes are harvested at early (1^{st}) ripening stage when they are hard-green but matured physiologically and climacteric respiratory peak has not occurred (Jha *et al*., 2006; Kienzle *et al*., 2011).

Postharvest storage efficiency of mango fruit should be extended for long period by using ethylene inhibitors (Sisler and Serek, 2003). Various chemicals have been used previously for regulation of fruit ripening in climacteric fruit such as nitrous oxide, nitric oxide (NO), methyl jasmonates, polyamines and 1-MCP (Khan and Singh, 2008; Zaharah and Singh, 2011). Previous studies showed positive effects of 1-MCP application on physiological (such as respiratory peaks, ethylene release, color, texture, decay rate and loss in weight) as well as biochemical parameters (soluble solids and acidity) of mango fruit during storage (Owino *et al*., 2012; Razzaq *et al*., 2015). Ripening delay mechanism of mango strongly influenced by concentration of 1-MCP, maturity stage, storage conditions and end use fruit quality (Watkins, 2008; Ayele *et al*., 2012; Rahman *et al*., 2016).

The challenge of fast urbanization and increasing export volume can only be met by improvement in postharvest

handling (Ghaffar, 2013). To our knowledge no such study has been conducting in Pakistan on commercial cultivars of mango at different maturity stages regarding postharvest application of 1-MCP during storage at low temperature. The objective of this research has been directed to find out the 1-MCP concentration to which mango varieties respond at its maximum level in terms of postharvest quality traits during storage.

MATERIALS AND METHODS

***Procurement of raw material*:** 'Langra', 'Dusehri' and 'Samar Bahisht (S.B.) Chaunsa' are commercially grown mango varieties in tropical areas of Pakistan. Fruit was harvested with 2 to 3 cm long stalk attached on date A (2016) early in the morning to avoid the field heat shock from experimental mango orchard 9 and 32 square located at University of Agriculture Faisalabad (UAF). Harvesting was done at two maturity stages; M1: mature green hard stage; peel color 100% green, pulp color light cream; and M2 as sprung green stage with 20 to 25% yellow peel color and slight yellowish tinge in pulp color. After harvesting, fruit was immediately transported to Food processing hall of National Institute of Food Science and Technology, UAF. Fruit was rested at room temperature (25°C) to remove field heat and harvesting stress for one hour. Fruit sorting was done by the removal of major defects for clean, healthy, diseased and damaged free fruit, with no signs of external blemishes and wounds. De-sapping was done in large container of 30 dm^3 by trimming the stem to 0.5 inch or 12.7 mm in lime water [0.5% $Ca(OH)_2$] solution to avoid the chances of sap (exudate from cut stem) contact with the fruit surface.

***Hot water dipping*:** After de-sapping, hot water treatment (HWT) was given at 52°C for 5 min along with fungicide (0.5 mL\LSportak®, *a.i.,* Prochloraz) application as described by Anwar and Malik (2007). A thermometer was placed into the water (in a bucket containing fungicide solution at canning hall) to check water temperature. After HWT, fruit was cooled at ambient temperature (25 to 27°C) for two hours and graded on shape and size basis (fruit got cut during de-sapping was also discarded).

***Treatment plan*:** 1-MCP [EthylBloc, Rohm and Hass Japan, Inc., active ingredient (*a.i.,*) 3.3%] powder was used for the preparation of stock solution of gaseous 1-MCP. Measured quantity of powder was taken in a vial as stated by Singh *et al*. (2007) and Singh and Dwivedi (2008). Small amount of water was added into vial and let it to mix with powder while shaking to release 1-MCP gas. Immediately within one minute, vial was opened into air tight glass bottle of known volume (Iqbal *et al*., 2018). Equal quantity of fruit samples were separated from both maturity stages of each variety. Fruit was equally distributed among five batches from each maturity stage for 1-MCP application at 250, 500, 1000 and 2000 $nL \cdot L^{-1}$ concentration with control treatment at each maturity stage.

Each batch was placed separately into different air-tight buckets (70 L) having a septum in the lid. Different concentrations 0 (control), 250, 500, 1000 and 2000 $nL \cdot L^{-1}$of gaseous 1-MCP were administrated for 18 hours (h) at room temperature (25±1°C) before being vented. Buckets were shaken gently for equal distribution of gas with short intervals during whole treatment time. Untreated control fruit was also enclosed in similar buckets for the same duration. After treatment, buckets were vented and fruit were packed in commercially used cardboard boxes having holes on the opposite side and each box containing not more than 6 fruit. Boxes were placed in climate chambers (Memmert ICH s260 C; Germany) at 13±2°C temperature and 80 to 85% relative humidity (R.H.) for 30 days (d). Fruit was subjected to destructive (titratable acidity, total soluble solids, ripening index) and non-destructive analysis (weight loss and peel color) after being removed from storage chambers at each storage interval (10 d). Respiration rate of fruit was measured at every 3rd day throughout storage.

Analysis

***Total soluble solids (TSS)*:** Soluble solids contents of mango fruit was determined as percent soluble solids (°Brix) by randomly selecting three fruit per treatment by using the procedure as described by AOAC (2003) with the help of hand held refractometer (Atago Co., Tokyo, Japan) at room temperature (20°C).

***Titratable acidity (TA)*:** Titratable acidity of mango juice was calculated by neutralizing the acid present in the known volume of juice till end point as stated by AOAC (2003). 10 mL of mango juice was taken into 50 mL beaker and titratable acidity was determined by titrating juice against 0.1 N NaOH solution until light pink color appeared. Phenolphthalein (two drops) was added as indicator. Beaker was constantly swirled to keep it thoroughly mixed and avoid the chances of direct contact of NaOH solution to the walls of the beaker. Volume of the NaOH solution used for titration was noted and fruit acidity expressed in equivalent (meq.) citric acid, calculated by using the following formula as shown in equation (3.1).

$$TA\ (\%) = \frac{Volume\ (mL) of\ NaOH \times Normality\ of\ NaOH\ \times Acid\ meq.\ factor}{mL\ juice\ titrated} \times 100 \quad (3.1)$$

***Ripening index (RI)*:** Eating quality of mango depends upon the appropriate proportion of soluble solids and acidity value of ripened fruit. Ratio of these two parameters known as ripening index. RI was measured (AOAC, 2003) by using the equation (3.2).

$$RI = \frac{TSS}{TA} \quad (3.2)$$

***Respiration rate (mmoles $CO_2 \cdot kg^{-1} \cdot h^{-1}$)*:** The rate of respiration was calculated after each harvesting following commencement of storage as stated by Zahara and Singh

(2011b). Six fruit was taken from each treatment and two fruit per replication was sealed at 20°C for 1 to 1.5 h in air-tight plastic box of 3 L capacity fitted with a rubber septum in the lid. Infrared CO_2 analyser (URAS-2, Mannesmann, Germany) was used for measurement of fruit respiration in terms of CO_2 production on the peak area basis of a 1.0 mL CO_2 standard (8.52±0.17 mmoles CO_2 in nitrogen). The respiration rate was expressed in mmoles $CO_2 \cdot kg^{-1} \cdot h^{-1}$ and measurements were performed at every third day in triplicate (equation 3.3). Data represented the means of three replications per treatment.

$$Respiration\ rate\ (mmol\frac{CO_2}{kg}.h) = \frac{\%CO2 \times Void\ volume\ (mL)}{Sample\ weight\ (kg) \times sealed\ time\ (h)} \times 100 \qquad (3.3)$$

***Loss in weight (%)*:** Five fruit per treatment was used for calculating physiological weight loss on fresh fruit basis and expressed as % weight loss as stated by Yadav *et al*. (2013). The same five fruit of each treatment were labeled and used during whole storage period. Results were expressed as average of all five fruit of each treatment to represent the weight loss in corresponding treatment. Weight loss during storage was determined by taking weight difference, divided by initial weight as shown in equation (3.4).

$$WL(\%) = \frac{Wi - Wf}{Wi} \times 100 \qquad (3.4)$$

where: *WL* is weight loss in percentage (%), *wi* is the initial weight at the beginning of the experiment and *wf* is final weight at end of experiment.

***Fruit peel color*:** Peel color of each variety was determined by following a 7-point color scale moved from 1 to 7 based on saturation of green to yellow color: 1 = 0% yellow or 100% green, 2 = breaker (< 20%) yellow, 3 = ¼ (25%) yellow, 4 = 25 to 50% yellow, 5 = 51 to 75% yellow and 6 = 76-100% yellow, 7 = yellow with black spots as previously stated by Jiang and Joyce (2000) with some modification (Dang *et al*., 2008).

***Statistical analysis*:** All determinations were performed in triplicates. The results were subjected to analysis of variance (ANOVA) by factorial arrangement (Maturity stage × 1-MCP conc. × storage interval) under completely randomized design (CRD) as outlined by Steel *et al*. (1997). Significant difference ($p \leq 0.05$) between variants were identified by means comparisons (Tuckey's test).

RESULTS

***Total soluble solids (TSS)*:** Maturity stage at harvesting showed significant effect ($P<0.05$) on total soluble solids of mango. Higher TSS contents were recorded at second maturity stage (M2) among treatments of each mango variety (Figure 1, 2, 3). Results demonstrated significant interaction effect ($p<0.05$) between concentration of 1-MCP and storage on TSS of three mango cultivars at each maturity stage. Fruit of control treatments showed maximum TSS contents in mango cultivars with no significant

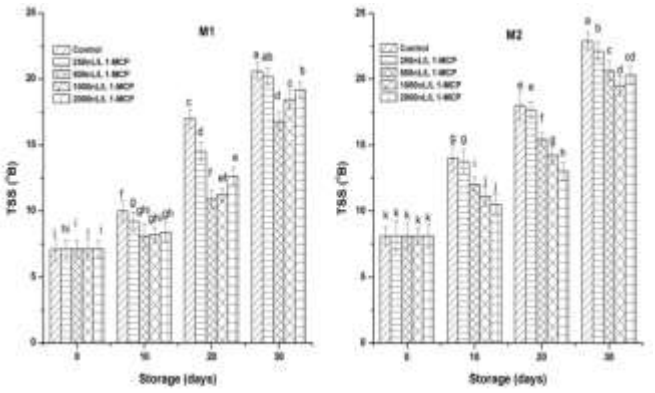

Figure 1. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on TSS of 'Langra' variety of mango at two harvesting stages (M1 & M2) during storage.

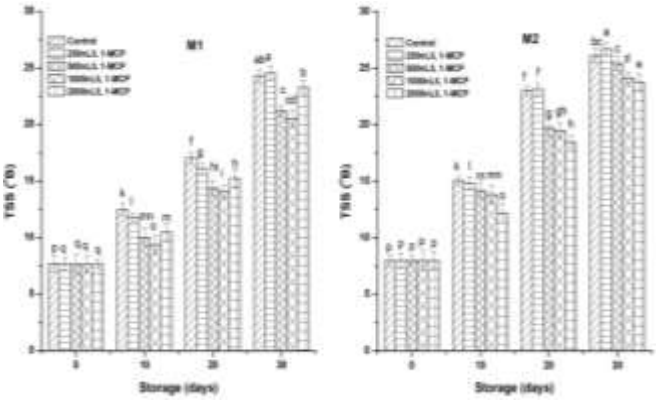

Figure 2. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on TSS of 'Dusehri' variety of mango at two harvesting stages (M1 & M2) during storage.

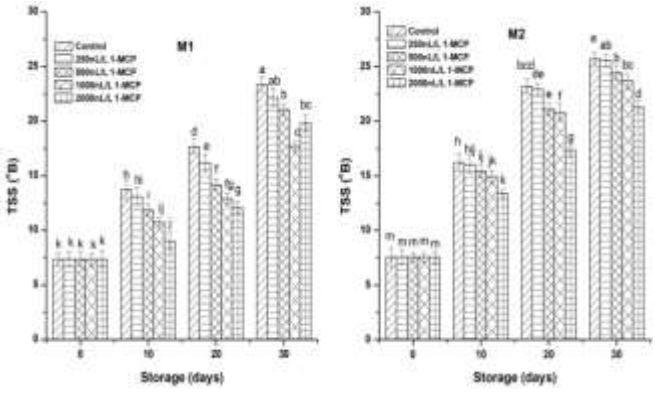

Figure 3. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on TSS of 'S.B. Chaunsa' variety of mango at two harvesting stages (M1 & M2) during storage.

difference at 250 $nL \cdot L^{-1}$ concentration of 1-MCP at each maturity stage. While more pronounced results were observed at higher concentrations of 1-MCP (500, 1000 & 2000 $nL \cdot L^{-1}$).

Each variety behaved differently at M1 stage as 1-MCP level varies between 250 and 2000 $nL \cdot L^{-1}$. Amongst 1-MCP treated fruit, least changes in TSS contents (7.11±0.84 to 18.95±0.92) was observed at 500 $nL \cdot L^{-1}$ concentration in 'Langra' variety till end of storage at M1 (Figure 1). TSS of mango cultivars followed increasing trend during storage among all treatments. This increment was found higher at M2 as compared to M1 stage (Figure 1, 2, 3). It was observed that as the concentration of 1-MCP increased, rise in TSS contents reduced gradually, but rapid rise was observed in fruit without 1-MCP exposure. Minimum total soluble solids was recorded at 2000, followed by 1000, 500 and 250 $nL \cdot L^{-1}$ concentration of 1-MCP at M2. In 'Dusehri' both 500 and 1000 $nL \cdot L^{-1}$ concentrations were found effective in terms of least variation in TSS contents (7.64±0.9 to 21.19±0.47; 7.65±0.74 to 20.51±0.75) and non-significant difference was observed among fruit of both treatments (Figure 2). Significantly reduced variations in TSS (7.34+0.67 to 17.71+0.43) was recorded in fruit at 1000 $nL \cdot L^{-1}$ concentration of 1-MCP in 'S.B. Chaunsa' variety during storage (Figure 3).

***Titratable acidity (TA)*:** Titratable acidity contents varies among mango varieties with highest contents in 'Dusehri' 0.87±0.019 and 0.79±0.06 % (Figure 4), followed by 'Langra' 0.83±0.011 and 0.75±0.04% (Figure 5) and 'S.B. Chaunsa' 0.80±0.021; 0.71±0.09% (Figure 6) at M1 and M2 stage, respectively. It is obvious from the results that higher acidity contents were recorded at M1 stage. No significant difference was observed at 10th day of storage among treatments at M1 stage in 'Langra' variety (Figure 4). Gradual reduction was observed on later days of storage with minimum changes were noted at 500 $nL \cdot L^{-1}$ in 'Langra' and at 1000 $nL \cdot L^{-1}$ 1-MCP in 'Dusehri' (Figure 5) and 'S.B. Chaunsa' varieties (Figure 6). Titratable acidity contents reduced rapidly at M2 during storage which was best maintained upto 1000 $nL \cdot L^{-1}$ 1-MCP in all three varieties. 'Dusehri' and 'S.B. Chaunsa' varieties under 2000 $nL \cdot L^{-1}$ concentration of 1-MCP showed good retention of titratable acidity contents at 10th and 20th day of storage, respectively, but was not found effective at 30th day of storage.

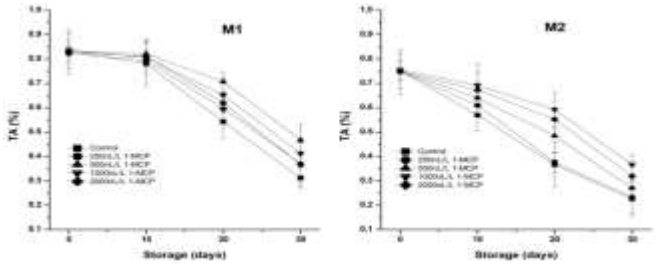

Figure 4. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on TA of 'Langra' variety of mango at two harvesting stages (M1 & M2) during storage.

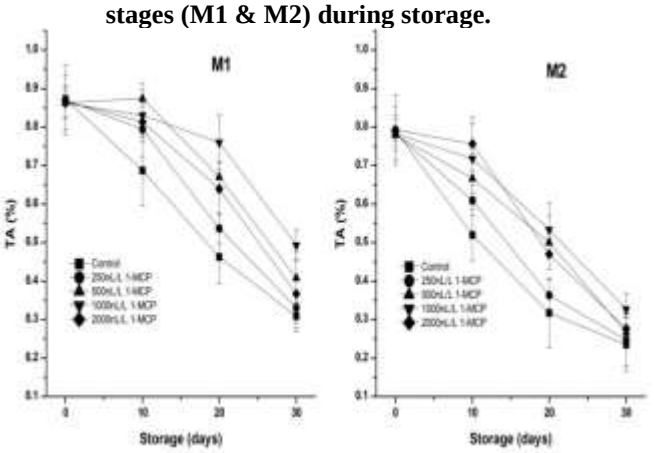

Figure 5. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on TA (%) of 'Dusehri' variety of mango at two harvesting stages (M1 & M2) during storage.

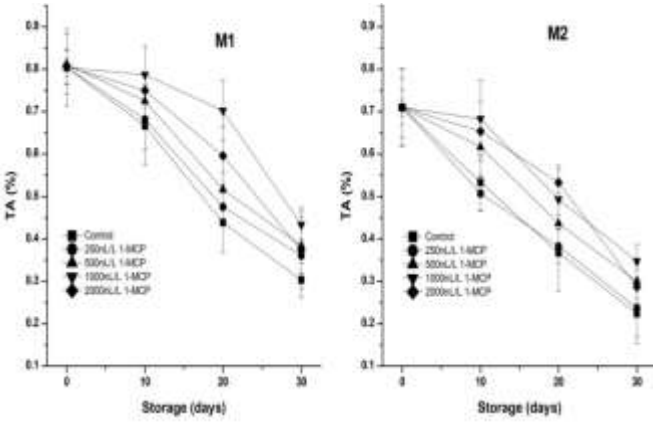

Figure 6. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on TA (%) of 'S.B. Chaunsa' variety of mango at two harvesting stages (M1 & M2) during storage.

***Ripening index (RI)*:** Maturity stage at harvesting showed variation ($p<0.05$) in terms of ripening index of mango varieties. Fruit harvested at M1 stage, exhibited reduced ripening rate as compared to M2 (Figure 7, 8, 9). It is cleared from the Figure 7 that least ripening index was observed in 'Langra' (8.49±1.74; 10.78±2.21), followed by 'Dusehri' 8.80±4.91; 10.09±2.91 (Figure 8) and 'S.B. Chaunsa' 9.10±2.21; 10.60±2.56 (Figure 9) varieties at M1 and M2 stage, respectively on harvesting date. Increasing trend in ripening index was recorded during storage among treatments, however delayed ripening was observed at M1 stage. This delay in ripening was prominent under 1-MCP treated fruit, while control treatment showed highest values

i.e., 66.24±3.00, 78.76±3.51, and 77.03±3.40 in 'Langra' (Figure 7), 'Dusehri' (Figure 8) and 'S.B. Chaunsa' (Figure 9), respectively at 30th day of storage. 'Langra' variety showed reduced ripening at intermediate level (500 $nL \cdot L^{-1}$) of 1-MCP, but as the 1-MCP concentration increased, ripening rate did not reduce equivalently during storage (Figure 7). At the 2nd harvesting stage (M2) gradual suppression in ripening rate was recorded in 'Langra' and 'S.B. Chaunsa' varieties with the increment of 1-MCP dose (from 0 to 2000 $nL \cdot L^{-1}$) till 20th day of storage. As storage proceeded (30th day interval), fruit under 2000 $nL \cdot L^{-1}$ of 1-MCP treatment showed comparatively higher RI than 1000 $nL \cdot L^{-1}$ of 1- MCP in both varieties (Figure 7 & Figure 9). In 'Dusehri', ripening index under 500 and 2000 $nL \cdot L^{-1}$ of 1-MCP treatment was not statistically significant ($p<0.05$) at 20th day, with lowest ripening rate observed in 1000 $nL \cdot L^{-1}$ of 1-MCP (Figure 8). Conclusively all three varieties 'Langra', 'Dusehri' and 'S.B. Chaunsa' experienced the lowest ripening rate (47.22±2.594, 73.80±2.594, 68.01±4.51) in 1000 $nL \cdot L^{-1}$ of 1-MCP concentration, respectively at storage ends followed by 2000 $nL \cdot L^{-1}$ of 1-MCP.

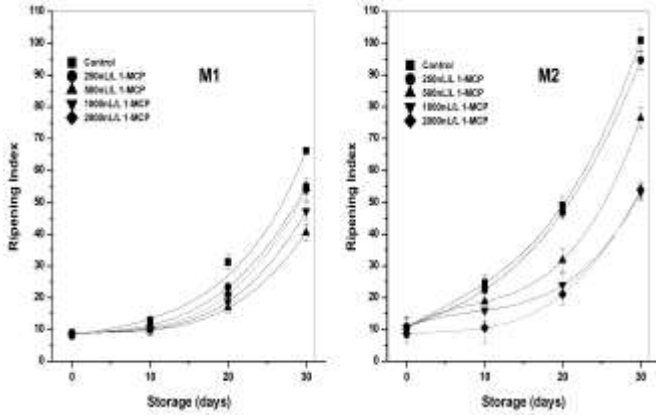

Figure 7. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on RI of 'Langra' variety of mango at two harvesting stages (M1 & M2) during storage.

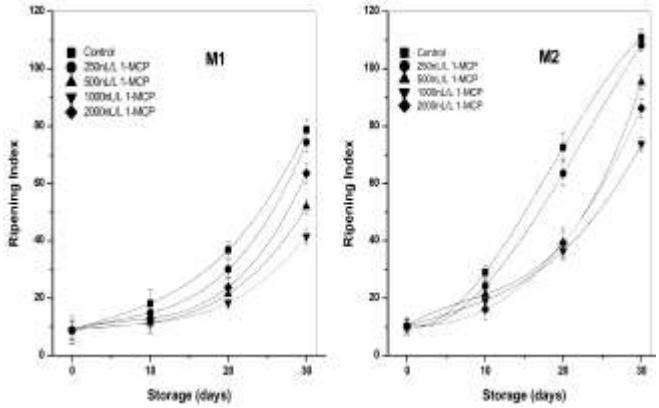

Figure 8. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on RI of 'Dusehri' variety of mango at two harvesting stages (M1 & M2) during storage.

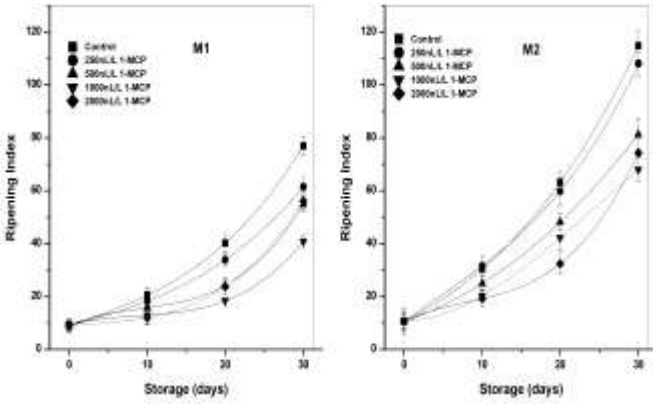

Figure 9. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 $nL \cdot L^{-1}$) on RI of 'S.B. Chaunsa' variety of mango at two harvesting stages (M1 & M2) during storage.

***Respiration rate (RR)*:** Maturity stage showed strong influence on production rate of CO_2 because lower respiration rate (1.31±0.14; 1.41±0.27 and 1.11±0.35 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$) was observed at M1 stage (Figure 10) in 'Langra', 'Dusehri' and 'S.B. Chaunsa' varieties, respectively on harvesting date. This trend was observed among all varieties till climacteric phase, *i.e.*, RR of M1< RR of M2 with some exceptions on later storage intervals during post-climacteric phase.

Respiration rate influenced by the 1-MCP concentration as cleared from the Figure 10, which indicates statistically significant interaction ($p<0.05$) between maturity stage, 1-MCP concentration and storage interval. Fruit respiration increased gradually during storage with the passage of time until climacteric phase (highest respiration rate) reached depending upon the maturity stage and 1-MCP concentration. Fruit under 1-MCP treatment showed fewer rises in respiratory peak than control at both maturity stages. 'Langra' variety at M2 stage showed no variation in climacteric phase (15th day) among treatments and lowest respiratory peak was recorded at 2000 (6.97±0.88 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$), followed by 1000 (7.56±0.39 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$), 500 $nL \cdot L^{-1}$ (8.17±0.41 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$) of 1-MCP. M1 stage showed respiratory climacteric peak on 15th day under 0 to 500 $nL \cdot L^{-1}$of 1-MCP concentration, while 3 days shifting in climacteric peak of 'Langra' fruit was found at 1000 and 2000 $nL \cdot L^{-1}$ of 1-MCP. Fruit undergo sudden fall in respiration rate after climacteric rise among treatments, known as post-climacteric phase (Figure 10). Fruit of 'Dusehri' variety did not observe respiratory peak till 12th and 9th day at M1 and M2 stage, respectively, among treatments. Intermediate levels

of 1-MCP *i.e.*, 500 (7.16±0.79) and 1000 nL·L^{-1} (6.44±1.19 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$) significantly suppressed the respiration rate with climacteric escalation on 18th day at M1 stage. In 'S.B. Chaunsa' variety delayed onset of respiratory peak (8.12±0.88 mmoles $CO_2 \cdot Kg^{-1} \cdot h^{-1}$) was recorded on 18th day under 1000 nL·L^{-1} level of 1-MCP at M1 maturity stage. Reduced respiration rate was observed under post-climacteric phase with small variation ($p>0.05$) at different storage intervals.

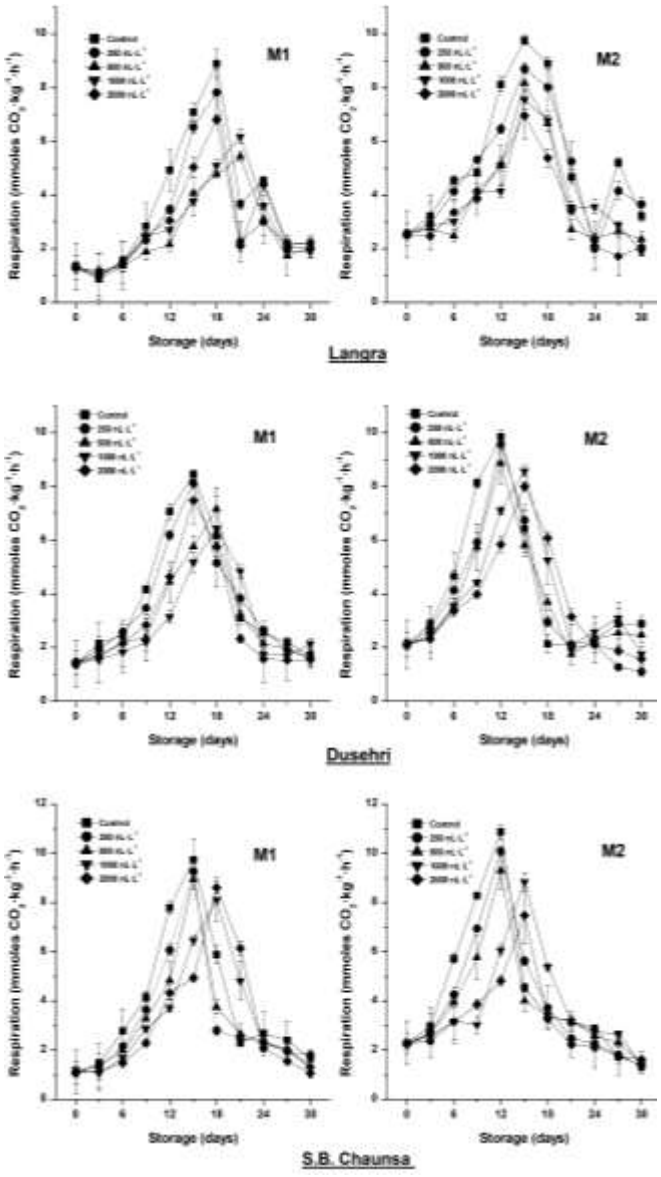

Figure 10. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on respiration rate (mmoles $CO_2 \cdot kg^{-1} \cdot h^{-1}$) of 'Langra', 'Dusehri' & 'S.B. Chaunsa' variety of mango at two harvesting stages (M1 & M2) during storage.

***Fruit peel color (score)*:** Statistically non-significant ($p = 0.56$) results for color score at M1 (3.19) and M2 (3.24) maturity of 'Langra' was obtained as depicted in Figure 11. Similarly, pre-storage exposure of 1-MCP concentration was not statistically at par ($p = 0.22$) for peel color of 'Langra' variety. Conclusively, 'Langra' variety remained green and no color changes in fruit peel was observed irrespective of harvesting maturity and 1-MCP concentration. While harvesting maturity stage and 1-MCP concentration significantly ($p<0.05$) influenced color development of mango in 'Dusehri' and 'S.B. Chaunsa' varieties. Rate of yellow color development was higher at M2 (6.58, 6.26) than M1 (5.91, 5.96) in 'Dusehri' and 'S.B. Chaunsa', respectively. 1-methylcyclopropene suppressed the color breaking (yellowing) of mango fruit as highest score (6.98±0.21, 6.68±0.11) in 'Dusehri' and 'S.B. Chaunsa' (7.13±0.13, 6.46±0.34) was recorded among fruit having no 1-MCP exposure at M2 and M1, respectively. The color score decreased as the 1-MCP exposure concentration increased with least color score (5.15±0.21) was gained by 1000 nL·L^{-1} of 1-MCP followed by 500 nL·L^{-1} (5.45±0.34) in 'Dusehri'. Least color score was recorded at 2000 and 1000 nL·L^{-1} of 1-MCP at M2 and M1 stage, respectively, in 'S.B.Chaunsa' variety (Figure 11).

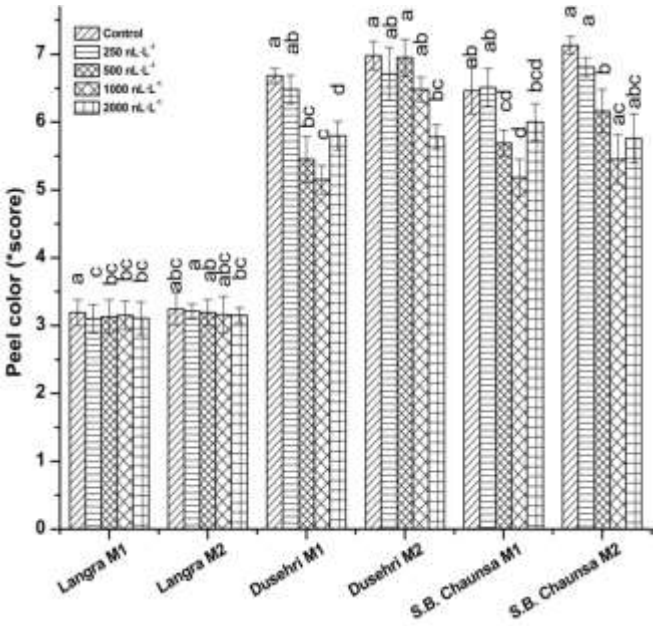

Figure 11. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on peel color (score*) of 'Langra', 'Dusehri' & 'S.B. Chaunsa' varieties of mango at two harvesting stages (M1 & M2) on day 30 of storage.

*1 = 0% yellow; 2 = breaker (< 20%); 3 = 25% yellow; 4 = 25 to 50% yellow; 5 = 51 to 75% yellow; 6 = 76–100% yellow; 7 = yellow with black spots

***Physiological loss in weight (%)*:** Strong relationship was found between maturity stage and 1-MCP concentration regarding physiological loss in weight of mango varieties during storage. It is obvious from the Figure 12 that weight loss of mango changes as pre-storage 1-MCP concentration varied between 0 and 2000 nL·L^{-1}. The highest weight loss was observed in fruit having no 1-MCP application (7.67±0.38), while the lowest value (7.37±0.56) was documented at higher dose (1000 nL·L^{-1}) of 1-MCP followed by 500 nL·L^{-1} at M2 stage in 'Langra' variety. 'Dusehri' variety showed good results when fruit exposed between 500 and 1000 nL·L^{-1} of 1-MCP at both harvesting stages. 'S.B. Chaunsa' showed statistically non-significant ($p>0.05$) reduction in weight among fruit treated at 500 and 2000 nL·L^{-1} of 1-MCP at M1. While at M2 stage 1000 nL·L^{-1} of 1-MCP found helpful in reducing % weight loss and maintaining the freshness of mango fruit.

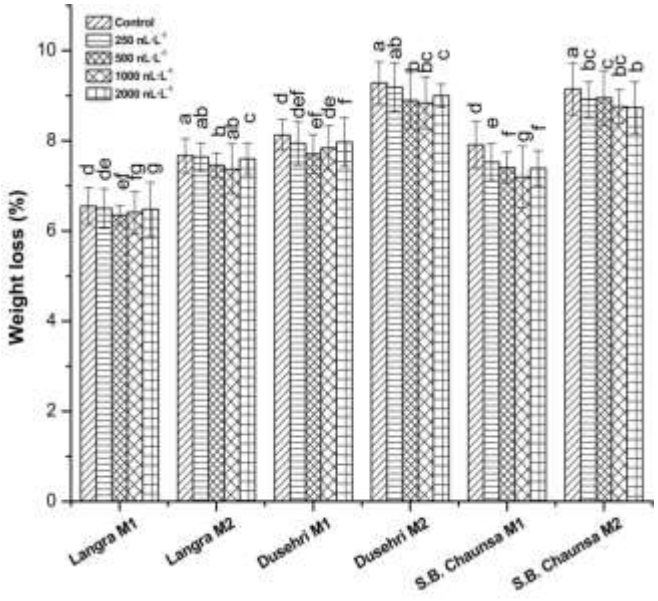

Figure 12. Effect of pre-storage application of 1-MCP (0, 250, 500, 1000 and 2000 nL·L^{-1}) on weight loss (%) of 'Langra', 'Dusehri' & 'S.B. Chaunsa' varieties of mango at two harvesting stages (M1 & M2) on day 30 of storage.

DISCUSSION

It was obvious from the results of the present study that mango fruit responded independently to different levels of 1-MCP treatment at two maturity stages. Some responses are common, however, most of them are unique depending upon the time (instant or delayed after harvesting) of application, stage (early or late stage of fruit) of application, dose of the chemical and length of the storage period (Mir *et al*., 2001; Watkins and Nock, 2005; Watkin, 2008). Results regarding total soluble solids and titratable acidity (TA) showed increasing trend of these parameters during storage. However, this increment was found more rapid at M2 (sprung stage) compared to M1 *i.e.*, mature green stage (Lalel *et al*., 2003a). The results showed that efficiency of 1-MCP treatment decreased with the advancement of ripening stage. That's why effect of 1-MCP was more pronounced at mature green stage even at lower concentration (250 to 1000 nL·L^{-1}) when similar concentration was applied at sprung stage (Mir *et al*., 2001; Jacomino and Kluge, 2002; Alves *et al*., 2004; Bron and Jacomino, 2006).

In 'S.B. Chaunsa', rise in TSS or loss of titratable acidity delayed as 1-MCP dose increased from 0 to 2000 nL·L^{-1}. Several studies reported ripening process delaying under 1-MCP application (Zhang *et al*., 2012) by irreversible binding to the ethylene receptors due to decreased rate of ethylene production (Serek, 1994). Hence, lowered ripening rate causes reduced conversion of starch molecules into simpler units such as sucrose and glucose ultimately responsible for decreased TSS contents of the fruit (Nunes, 2007). This effect was prominent at mature green stage (M1). Higher TSS was observed at M2 due to enhanced ripening and increased conversion of starch molecules into sugars (Zhong *et al*., 2006; Abbasi *et al*., 2009).

TA contents were found higher among 1-MCP treated fruit at both maturity stages than the control ones as cleared from the results. 1-MCP treatment helped in preserving the organic acids of the fruit by lowering the respiratory metabolism during storage (Abbasi *et al*., 2009; Cocozza *et al*., 2004; Razzaq *et al*., 2013). The higher TSS contents and reduced titratable acidity recorded at end of storage period among the treatments of M2 than M1. The observed difference among two maturity stages could be due to the incidence of rapid rate of ripening at M2 as previously documented by the Alves *et al*. (2004) while studying 1-MCP treated 'Tommy Atkins' at two maturity stages. 1-MCP in 2000 nL·L^{-1} was not found good enough among all varieties because higher dose effect negatively on ripening characteristics of the mango such as uneven ripening and de-greening reduced flavor and air pockets development in mango (data not shown). As the storage proceeded, these changes pushed fruit into stress resulting in increased rate of respiration and abnormal ripening as compared to 500 and 1000 nL·L^{-1} 1-MCP. When mango varieties treated with lower dose of 1-MCP 500 and 1000 nL·L^{-1}, non-permanent binding of 1-MCP to ethylene receptors, could be turned back and led fruit to ripe normally with reduced but steady ripening rate (Blankenship and Dole, 2003).

Ripening index of fruit increased with the passage of time however less rises was observed at M1 stage under 1-MCP exposure. This reduction in SSC/TA ratio (ripening index) could be due to lowered TSS contents and increased fruit acidity among 1-MCP treatment as stated by Liu *et al*. (2010) while studying effect of 1-MCP treatment on 'Zihua' mango

variety. During ripening, organic acids acted as respiratory substrate and converted into sugar molecules. Hence, TSS contents increased and titratable acidity decreased more rapidly in control treatments during storage (Razzaq *et al*., 2015).

Climacteric respiration peaks were observed significantly lower under 1-MCP treatment in 'Langra', 'Dusehri' and 'S.B. Chaunsa' varieties. Similar results were reported previously in other climacteric fruit such as banana, plum, avocado, soursop (Golding *et al*., 1998; Jeong and Huber, 2004) and Kent and Tommy Atkins mango varieties (Alves *et al*., 2004; Hershkovitz *et al*., 2005). Reduction in peak height as 1-MCP concentration increased could be due to blocking (competitive inhibition) of ethylene binding sites by formation of 1-MCP+active site complex (Serek *et al*., 1994), resulting reduced autocatalytic ethylene production (Blankenship and Dole, 2003) and ultimately delayed ripening of fruit (Lalel *et al*., 2003). This reduction in ripening resulted in reduced respiration under 1-MCP application compared to control as previously documented (Lalel *et al*., 2003; Penchaiya *et al*., 2006; Chaiprasart and Hansawasdi, 2006). At lower concentration of 1-MCP, suppression in respiration rate was not prominent at M2 while at M1 effects were more pronounced. Conclusively reduced respiration rate was observed at M1 than M2 with some exceptions on later storage intervals during post-climacteric phase (which might be due to fruit decaying and improper ripening, ultimately pushing fruit into stress). These results were coinciding with the findings of Alves *et al*. (2004) while studying Tommy Atkins, apple (Mir *et al*., 2001) banana (Golding *et al*., 1998; Jiang *et al*., 2000) and tomato (Wills and Ku, 2002).

Least color development was noted in fruit having 1-MCP exposure than those who have no 1-MCP application (control). But more rapid changes in color was occurred at M2 (sprung stage) compared to M1 (mature green) stage. 1-MCP delayed color development with gradual rise in yellowing due to ripening retardant mechanism as documented previously by Chaiprasart and Hansawasdi (2006). Similar results were reported by Penchaiya *et al*. (2006) in 'Nam Dokmai' and Faasema *et al*. (2014) in 'Peter', 'Brokin' and 'Julie' mangoes. In fruit having no 1-MCP treatment, yellowing of fruit was rapid might be due to increased activity of chlorophyll degrading enzymes resulting in synthesis of carotenoids in peel (Brecht and Yahia, 2009) which is main color pigment contributing yellow and orange color to the mango (Singh *et al*., 2013). Along with the chlorophyll degradation many other regulatory mechanisms (complex feedback mechanism) at cell level are involved in carotenoids accumulation of mango during ripening. Mango chloroplasts (ultrastructure's of chloroplasts from mango mesocarp) contained many plastoglobuli (varying in size) comprised the main part of carotenoids which impart yellow color to mango during ripening (Vasquez-Caicwdo *et al*., 2006; Nisar *et al*., 2015). Nevertheless, fruit of control treatment including M2 stage developed more yellow color at end of storage.

***Conclusion*:** It can be concluded that mango varieties behaved independently to different levels of 1-MCP depending upon the maturity stage of fruit. However, variation exists among fruit harvested at same maturity stage, when exposed to different concentrations of 1-MCP. 1-MCP concentration between 500 and 1000 $nL \cdot L^{-1}$ showed better chemical composition and reduced ripening and respiration rate among mango varieties at commercial maturity stage (M1). In fruit harvested at advanced maturity (M2), higher levels (1000 to 2000 $nL \cdot L^{-1}$) of 1-MCP was found effective in maintaining good postharvest quality traits.

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