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ORIGINAL ARTICLE / ORIGINALBEITRAG

Postharvest Methyl Jasmonate Alleviates Chilling Injury and Maintains Quality of 'Kinnow' (*Citrus Nobilis* Lour *x C. deliciosa* Tenora) Fruits Under Differential Storage Temperature

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Abstract

Application of novel generally recognized as safe (GRAS) chemicals may help in preserving the health promoting compounds and esthetic value of the 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits. The aim of this study was to evaluate the effect of exogenously applied methyl jasmonate (MeJA) at differential storage temperatures on the postharvest quality of 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits. Physiologically mature freshly harvested fruits were treated with the different concentrations of MeJA, i.e., 0.1 mM, 0.3 mM, 0.5 mM, 0.7 mM and control for 5 min and air dried for 10 min. The treated fruits were stored consecutively at two different temperatures of 2 °C for 20 days and at 6 °C for 20 days at 85–95% relative humidity. Results showed that MeJA treated fruits maintained better quality of 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits than control during the entire storage period. Fruits treated with MeJA (0.5 mM) and stored at differential temperatures significantly delayed the loss in fruit weight, maintained firmness, maintained higher total soluble solids (TSS), total phenols content (TPC), ascorbic acid (AA), antioxidant activity (AOX) and lower titratable acidity (TA) content with zero chilling injury (CI) under a cold storage period of 40 days. Also, MeJA (0.5 mM) treatment showed higher overall sensory attributes, making the fruits more acceptable to consumers after 40 days of storage. In conclusion, postharvest application of MeJA (0.5 mM) at differential temperatures proved an effective and safe strategy to enhance the quality and shelf-life of 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits.

Keywords Citrus · Hormone · Cold storage · Antioxidants · Sensory

Introduction

'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) is one of the most popular citrus fruits because of its peculiar characteristics like attractive golden yellow coloured, loose, thin, easy-to-peel rind, easily separable segments and excellent flavor with abundant amount of nutrients. Fruits are endowed with phytochemcials including high phenols and antioxidants (Baswal et al. 2020). Fruits contain sodium (0.01–0.03 mg/g), potassium (1.6–2.5 mg/g), calcium (0.14–0.47 mg/g) and many secondary metabolites such as limonoids, flavones, phenolics, flavonoids and carotenoids (de Moraes Barros et al. 2012; Purewal and Sandhu 2020). Moreover, exogenous application of generally recognized as safe (GRAS) chemicals has been reported to be beneficial in increasing the level of bioactive compounds such as phenols and antioxidants (Baswal et al. 2020; Haider et al. 2020). Fruit peel is a rich source of low methoxyl pectin that can be used for making low calorie jam, jelly, marmalades, candies and pharmaceutical preparations due to high functionality (Ghoshal and Negi 2020). Fruits are stored under low temperature to maintain their marketable quality for longer period but encounter several problems related to low temperature stress, pathogenic infection and undesirable changes (chilling, pitting, browning, off flavour). Chilling injury (CI) being a major obstacle when fruits are exposed to low temper-

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ature for longer duration, causes loss of cellular integrity due the degradation of membrane lipids (Sanchez-Ballesta et al. 2006), thereby lowering the quality and marketability of the fruits.

Different synthetic chemicals and biodegradable materials are used to minimize these problems but are not appreciated due to increasing consumer concern for health as well as environmental safety (Bhan et al. 2022). Inducing defense mechanism and resistance in fruit itself during postharvest storage is now becoming an effective and non-toxic approach to enhance the quality and shelf-life of stored fruits (Terry and Joyce 2004). Recently, use of GRAS biomolecules such as salicyclic acid (SA), brassinosteroids (BRs), melatonins (MT), N_2O, plant extracts, methyl jasmonate (MeJA) have been gainfully utilized to induce defense system, antioxidant activity, bioactive compounds and shelf-life of 'Kinnow' fruits (Lv et al. 2018; Baswal et al. 2020, 2021; Bhan et al. 2022). Previous studies demonstrated that MeJA treatment could alleviate the chilling injury, enhance the availability of bioactive compounds and food value by accelerating defense enzymes and other metabolic changes in apple (Lv et al. 2018), grapefruit (Ahmed et al. 2015), blood orange (Habibi et al. 2019) and 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) (Baswal et al. 2020; Dhami et al. 2022).

MeJA being a natural signalling hormone modulates various plant defense system developing natural defenses against abiotic and biotic stresses, can be an effective approach to maintaining the quality of fruits (Wasternack and Hause 2013). Previous studies have shown that MeJA regulates various physiological processes through accumulation of pigments, phenolic compounds, antioxidants and sugars (Reyes-Diaz et al. 2016). MeJA enhances membrane integrity via reducing phospholipase D (PLD) and lipoxygenases (LOX) enzymatic pathway and increase fatty acid desaturases (FDA) and heat shock protein (HSP) gene expression, thereby alleviating CI in perishable fruits (Aghdam and Bodbodak 2013). It is reported that MeJA acts by increasing the AOX and phenolic content in order to enhance the chilling tolerance in fruits (Ghasemnezhad and Javaherdashti 2008). Application of MeJA have found to reduce CI in lemon at 2 °C (Siboza et al. 2014), increase phenolic content in kiwifruit (Pan et al. 2020) and increase antioxidant capacity of blueberry fruit (Wang et al. 2019), leading to improved health beneficial properties and postharvest quality of fruits.

Short-term low temperature conditioning of fruits helps in retaining stronger antioxidative systems and the internal defence system (Ahmed et al. 2015). Several studies suggest that low temperature exposure accelerated shelf-life by inducing defensive enzymes activities but prolonged storage may cause CI. In addition to that, accelerated temperature may enhance off flavour in citrus fruit and also has negative impact on sensorial properties (Marcilla et al. 2006). Low temperature conditioning of perishable commodities is likely used by commercial stakeholders to reduce the impact of CI. A study by Phong et al. (2018) revealed that low temperature conditioning of peach fruit at 6 °C followed by subsequent storage at 2 °C significantly reduced the incidence of CI. Low temperature conditioning at 16 °C for 7 days and storage at 5 °C alters the molecular mechanism of CI of grapefruit and significantly reduced it (Maul et al. 2008). Exogenous application of MeJA along with differential temperature could alleviate chilling injury, preserve phytochemicals and enhance shelf-life when used in an integrated manner. However, no such study has been conducted on exogenous application of MeJA at differential temperature in relation to shelf-life and quality retention of 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits.

The objective of this study was to assess the postharvest effects of MeJA on CI, AOX and sensory quality under differential storage conditions of 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits. In addition, other bioactive compounds such as fruit acidity, ascorbic acid and total phenolics were also evaluated. The present study helps in elucidating the probable mechanism and effects of MeJA on postharvest quality of 'Kinnow' mandarin at differential storage conditions.

Materials and Methods

Fruit Collection and Treatments

'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits were harvested at physiological maturity (total soluble solids [TSS]/Acid ratio 12:1), having uniform size and shape, from the experimental farm of the Division of Fruits and Horticultural Technology, ICAR-Indian Agricultural Research Institute, New Delhi (28.080° N, 77.120° E, 230 m above mean sea level), India, in the period 2019–2021. On the same day, healthy and uniform fruits were subjected to dip treatments with different concentrations of MeJA (0.1, 0.3, 0.5, 0.7 mM) and control (distilled water) for 5 min. Thereafter, fruits were air dried for 10 min and kept under two storage temperatures, i.e. 2 °C and subsequently at 6 °C at relative humidity of 85–95% for 40 days. Fruits were retained at 2 °C for 20 days followed by at 6 °C for another 20 days. The stored fruits were then finally analysed for various parameters at 10-day intervals up to 40 days. There were 40 fruits in each treatment and replicated thrice.

Analysis of Physical Parameters

The weight loss of fresh 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits was calculated at 10-day intervals of storage and calculated as the difference between the initial weight and the final weight of the fruit at the time of measurement and expressed as the percentage of initial fruit weight.

The CI (%) of fruits were visually examined for the symptoms on the basis in surface area scale of surface pitting and dark patches (browning) as described by Mohammadrezakhani): 0 = no symptoms; 1 = slight injury (1–25%); 2 = moderate injury (26–50%); 3 = severe injury (51–75%); and 4 = extremely severe injury (76–100%). The CI index was calculated using the following formula:

$$\mathrm{CI}(\%) = \Sigma(\text{CI scale}) \times (\text{Number of fruit at the CI level}) / (\text{total number of fruits in the treatment})$$

Fruit firmness was determined according to Bhan et al. (2022) in five randomly harvested mature fruits by texture analyzer (Model: TA + Di, Stable micro systems, UK) using 49 N load cell, 36 mm diameter cylinder probe with test speed-2 mm/s and distance-10 mm. Maximum force at its peak was interpreted as firmness and given in kilogram forces (kgf).

Analysis of Biochemical Parameters

Titratable acidity was determined by titrating the juice sample with 0.1 N NaOH using a few drops of 1% phenolphthalein solution as indicator and finally, acidity was expressed in percentage (%) (Dhami et al. 2022). TSS was analyzed by using hand refractometer (Fisher 0–50, Japan) and the reading was recorded in °B. Ascorbic acid content was estimated by the standard procedure using metaphosphoric acid (HPO_3), ascorbic acid standard and standardized dye of the sodium salt of 2, 6-dichlorophenolindophenol (Wang et al. 2019). The total phenol content was determined using Folin-Ciocalteu reagent (Singleton et al. 1999). The 0.1 ml sample extract (in 80% ethanol) was mixed with 0.5 ml Folin-Ciocalteu reagent, 2.0 ml Na2CO3 solution and 2.9 ml distilled water. Finally, the absorbance of the mixture was taken at 760 nm using a spectrophotometer (Model: Thermo Scientific™ GENESIS™ 180 UV-Visible Spectrophotometer) after 90 min where the mixture without sample was taken as blank. The total phenolics content was expressed in gallic acid equivalent (µg GAE g/FW).

AOX of fruit samples was determined by Ferric Reducing Antioxidant Power (FRAP) assay which works on the principle of reduction of a ferric-tripyridyltriazine complex to its ferrous (Fe2þ-TPTZ) complex under acidic conditions. The mean value of AOX was expressed in mg of Fe^{+}/100 ml of sample.

The sensory quality evaluation of the 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits was done by a semi-trained panel of 10 judges aged between 25 and 45 years of both genders, using a 9 point Hedonic scale (Asrey et al. 2020). Samples which obtained a score of 5.5 and above were considered as acceptable.

Data Analysis

The analysis of the present investigation was done through repeated measurement analysis in a two-factor ANOVA using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The mean comparison was performed using Tukey's Honest Significant test at the 5% level of significance ($p \leq 0.05$).

Table 1 Effect of MeJA on PLW, firmness and titratable acidity (TA) of the Kinnow fruits stored at differential temperature (2 °C and 6 °C) for 40 days

Treatments	PLW (%)					Firmness (kgf)					TA (%)				
	Storage (days)					Storage (days)					Storage (days)				
	0	10	20	30	40	0	10	20	30	40	0	10	20	30	40
MeJA (0.1 mM)	0	1.9	3.6	5.9	8.0	0.68	0.66	0.64	0.60	0.52	1.10	1.20	1.30	1.35	1.39
MeJA (0.3 mM)	0	1.8	3.5	5.7	7.7	0.68	0.67	0.65	0.60	0.53	1.10	1.23	1.32	1.39	1.43
MeJA (0.5 mM)	0	1.5	3.1	5.3	7.1	0.68	0.67	0.66	0.63	0.57	1.10	1.18	1.24	1.32	1.35
MeJA (0.7 mM)	0	1.6	3.2	5.5	7.4	0.68	0.64	0.65	0.62	0.56	1.10	1.28	1.35	1.43	1.48
Control	0	1.8	3.9	6.3	8.6	0.68	0.65	0.63	0.57	0.49	1.10	1.33	1.39	1.48	1.54
LSD ($P \leq 0.05$),	T = 0.102					T = 0.008					T = 0.008				
T = treatment	D = <0.0001					D = <0.0001					D = 0.0002				
D = day	T X D = 0.867					T X D = 0.0016					T X D = 0.324				

[a] Data represents mean of three replications ($n = 3$)

MeJa Methyl jasmonate, *PLW* Physiological losses in weight, *kgf* Kilogram force

Table 2 Effect of methyl jasmonate (MeJA) on total soluble solids (TSS), ascorbic acid (AA) and total phenols content (TPC) of 'Kinnow' fruits stored at differential temperature (2 °C and 6 °C) for 40 days

Treatments	TSS (°B)					AA (mg/100g)					TPC (µg GAE/g)				
	Storage (days)					Storage (days)					Storage (days)				
	0	10	20	30	40	0	10	20	30	40	0	10	20	30	40
MeJA (0.1 mM)	11	11.6	11.8	12.1	12.3	1.10	20.9	21.7	22.3	23.0	286.0	296.0	302.5	308.0	309.5
MeJA (0.3 mM)	11	11.8	11.9	12.3	12.6	1.10	20.9	21.9	22.7	23.4	286.0	301.5	309.5	316.5	318.0
MeJA (0.5 mM)	11	12.2	12.7	13.0	13.4	1.10	20.9	22.0	23.2	24.0	286.0	220.5	335.5	350.5	356.5
MeJA (0.7 mM)	11	12.0	12.4	12.7	13.1	1.10	20.9	22.2	23.0	23.7	286.0	317.5	328.0	340.0	343.5
Control	11	11.3	11.5	11.6	11.7	1.10	20.9	20.3	20.0	19.6	286.0	289.5	280.0	269.5	256.5
LSD ($P = 0.05$), T = treatment, D = day	T = 0.0001 D = <0.0001 T X D = <0.0001					T = <0.0001 D = <0.0001 T X D = <0.0001						T = <0.0001 D = <0.0001 T X D = <0.0001			

[a] Data represents mean value of three replications ($n = 3$)

Results and Discussion

Postharvest MeJA dip treatments significantly retained the quality parameters in the 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits; however, MeJA (0.5 mM) reduced CI and maintained overall better quality in the fruits during low temperature storage. The higher concentration may have counteracted the positive results on fruit quality by assisting ripening and the senescence process of the fruits (Jin et al. 2009).

Physiological Loss in Weight

Postharvest MeJA dip treatment significantly ($p \le 0.05$) delayed weight loss in the fruit compared to control fruits during the storage period (Table 1). The fruits treated with MeJA (0.5 mM) had significantly ($p \le 0.05$) lower weight loss (7.1%) compared to control (8.6%) fruits during cold storage. Weight loss during storage is the result of evapotranspiration of moisture from the produce due to elevated metabolic activities (Liao et al. 2022). Postharvest treatments of certain molecules and coatings helps in reducing the respiration and moisture loss by altering the physiology of fruits. Lower weight loss in treated fruits may be due to reduced respiration rate and senescence (Rasouli et al. 2019). MeJA generated free radicals leading to closed stomata of the tissues (Wolucka et al. 2005). Reduced weight loss has previously been shown in 'Kinnow' (Baswal et al. 2020), lemon (Liao et al. 2022) and arrayana mandarin (Gómez et al. 2017).

Fruit Firmness

Fruit firmness decreased with extended storage period in all the treatments; however, fruits treated with 0.5 mM MeJA retained significantly higher firmness (0.57 kgf) as compared to control fruits (0.49 kgf) on the 40th day of storage (Table 1). Fruit firmness is related with breakdown of middle lamella and pectic substances due to hydrolysis of starch. Exogenous application along with low temperature maintained higher skin strength. In addition, activity of pectolytic enzymes also influences the firmness (Bhan et al. 2022). MeJA treatment regulates the biosynthesis pathway of pectiolytic enzymes with down-regulation of the activities of pectinmethyl esterase and cellulosic activities, resulting in delayed loss of firmness. Dhami et al. (2022), Serna-Escolano et al. (2021) and Saracoglu et al. (2017) found similar results in 'Kinnow' mandarin (*Citrus nobilis* Lour *x C. deliciosa* Tenora), lemon and sweet cherry, respectively, which is attributed to ripening-retarding effects of MeJA and better cellular integrity of peel due to higher moisture content in fruits together may have contributed to higher retention of fruit firmness. Furthermore, maximum firmness retention may be attributed to restricted senescence processes such as ethylene synthesis, respiration, and cell wall breakdown (Baswal et al. 2020).

Titratable Acidity

Titratable acidity (TA) content showed increasing trend in all the fruits, but the lowest (1.35%) acidity was maintained in the 0.5 mM MeJA treated fruits as compared to the control (1.54%) fruits during the storage period as presented in Table 1. Citric acid is the chief organic acid in 'Kinnow' mandarin responsible for imparting acidity. Generally, acids are utilized as respiratory substrate during storage resulted decrease in acidity content (Bhan et al. 2022), but in our study the acidity content showed an increasing trend up to 40 days. MeJA (0.5 mM) application delayed the metabolic processes that results delayed loss in organic acids level and maintained higher level of acidity (Baswal et al. 2020; Haider et al. 2020). Moreover, conversion of sugars might also not initiate up to storage period. Previous studies have elucidated that the acceleration in acidity during storage

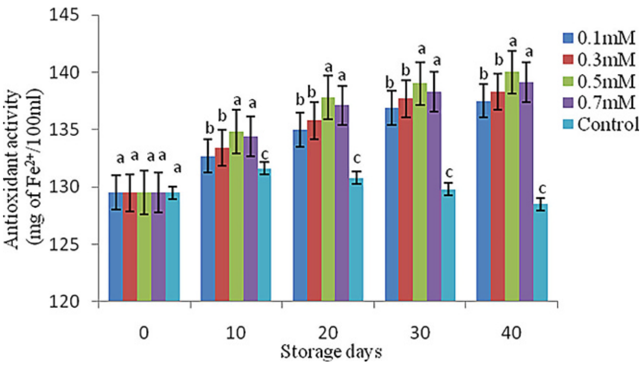

Fig. 1 Effect of the methyl jasmonate and differential temperature on the antioxidant activity of 'Kinnow' mandarin during cold storage of 40 days. The *vertical lines* show the error bar of standard error of three replications ($n = 3$). Mean with same superscript are not significantly different at $p \le 0.05$

period was owing to reduced rate of sugar conversion into acids or transpiration rate that helped in increasing the concentration of acids (Seehanam et al. 2010; Bisen et al. 2012; Miri et al. 2018). Miri et al. (2018) also reported that acidity content in 'Kinnow' was increased up to 30 days and then started declining slowly when coated with wax and packed in polyethylene. Furthermore, less TA in the MeJA treated fruits may be altogether due to ripening process producing sugars, higher moisture content in the fruits and utilization of acid compounds during storage period. Previously, Geransayeh et al. (2015) reported higher TA content in MeJA treated strawberry fruit and Serna-Escolano et al. (2021) in lemon.

Total Soluble Solids

There was significant increase in TSS content in the treated fruits as compared to control fruits during storage (Table 2). Among the treatments, MeJA (0.5 mM) treated fruits showed higher TSS (13.4 °B) compared to other treatments and control. TSS is a common quality trait that determines the acceptability of particular produce. Generally, TSS is likely increased during ripening and storage of fruits owing to catabolic processes of soluble compounds. The increased TSS content is directly associate with conversion of complex compounds (sugars, starches, acids, etc.) into simpler compounds. The hydrolysis of starch into sugars is a more important fact, associated with higher TSS in 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) (Dhami et al. 2022; Bhan et al. 2022). MeJA may have lowered metabolic activities and delayed the senescence process, thus increasing TSS in the fruits.

Ascorbic Acid

AA content in the MeJA treated fruits showed significant increasing trend; in contrast, control fruits showed decreasing trend during the storage period (Table 2). The highest AA content (24.0 mg/100 g) was found in MeJA (0.5 mM) treated fruits and the lowest (19.6 mg/100 g) in control fruits on the 40th day of storage. AA is highly sensitive to oxidation process during storage of fruits and vegetables. MeJA treatment helps in delaying that catabolic process which uses AA as a substrate, and it is well known that altering the activity of dehydroascorbatase might be one of the reasons for preserving higher AA in treated fruits (Dhami et al. 2022). The increasing trend in AA content in fruits can be co-related with the enhancing property of MeJA causing transcription of genes involved in the de novo biosynthesis of ascorbic acid as illustrated in the reports through experiments on plant cells (Wolucka et al. 2005). A similar increase in ascorbic acid content was reported in mandarin (Baswal et al. 2020) and blueberry (Wang et al. 2019).

Total Phenols Content

Changes in total phenols content (TPC) due to MeJA and differential temperature are presented in Table 2. MeJA treatment significantly enhanced the value of TPC during storage. As data shown in Table 2, 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruit treated with MeJA (0.5 mM) had the maximum (356.5 µg GAE/g) TPC compared to control on 40th day of cold storage. According to De Geyter et al. (2012), MeJA causes activation of secondary metabolic pathways leading to accumulation of phenolics compounds, subsequently increasing total phenols in the treated fruits. Furthermore, exogenous application has been reported to increase the biosynthesis efficacy of phenyl ammonia lyase enzymes, resulting in greater phenolic content in treated fruits (Wang et al. 2019). Similarly, an increase in phenolic content was reported in kiwifruit (Pan et al. 2020) and grapes (Flores et al. 2015).

Antioxidant Activity

The AOX of MeJA treated fruits significantly ($p \le 0.05$) increased; however, this initially increased but overall decreased in control fruits with the extended storage period (Fig. 1). The mean AOX value was noted to range from 126 to 139 mg of Fe^{+}/100 ml in various treatments. The highest amount of AOX was found in MeJA (0.5 mM) treated fruits among all other treatments. Antioxidants are the major secondary metabolites offering numerous health benefits. Several compounds such as phenolics, ascorbic acid, pigments and flavonoids are major antioxidant contributory factors. The application of MeJA enhanced the activities of

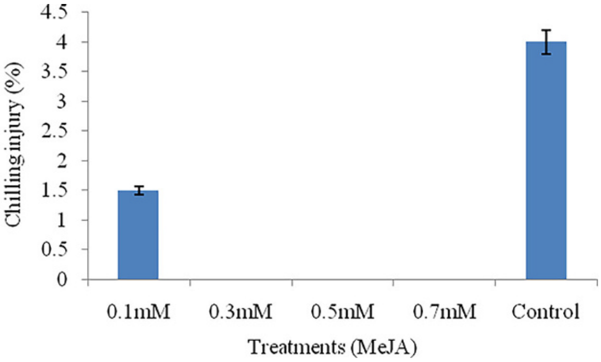

Fig. 2 Effect of methyl jasmonate and differential temperature on chilling injury of 'Kinnow' mandarin during cold storage of 40 days. The *vertical lines* show the error bar of standard error of three replications ($n=3$)

antioxidative enzymes which might retain the oxidation of antioxidant compounds. Furthermore, it is also well documented that cold storage induces the accumulation of phenol compounds in fruits. MeJA also regulates the pathways of several phenolics and enzymes. Therefore, in 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits, MeJA delayed the catabolic processes and degradation of such compounds. Additionally, MeJA treatment also preserved the ascorbic acid content and phenolics, which are the key contributory compounds in AOX value. Asghari and Hasanlooe (2015) reported that MeJA operates on the many pathways associated with the antioxidant system, hence increasing antioxidant capacity. The application of MeJA showed similar results in pomegranate, sweet oranges and mandarin in an experiment conducted by Garcia-Pastor et al. (2020), Rehman et al. (2018) and Dhami et al. (2022), respectively.

Chilling Injury

Figure 2 shows the appearance of CI (%) after 40 days of cold storage. No CI symptoms were observed in any MeJA treated fruits except control and 0.1 mM MeJA treated fruits, which had 1.5% on the 40th day of storage. However, 4% CI was observed in the untreated (control) fruits during the storage which was significantly ($p \leq 0.05$) higher over the treatment (Fig. 3). The cell membrane is the main site that is more affected due to CI. Increased chilling tolerance during cold storage in MeJA treated 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits can be associated with the reduced membrane disruption and leakage, increased activity of phenylalanine ammonia lyase (PAL), ascorbic acid, total phenols content and antioxidants activity in the fruits. Previously, Siboza et al. (2014) reported increased activity of PAL, phenolics and antioxidants in MeJA treated lemon, where flavedo might have protected fruits against CI. Moreover, MeJA treatments also reduced the accumulation of reactive oxygen species (ROS) and oxidative stress, which is known to be associated with the incidence of CI (Rehman et al. 2018).

Sensory Evaluation

As shown in Fig. 4, sensory parameters such as texture, taste, flavour and colour in MeJA treated 'Kinnow' (*Citrus nobilis* Lour *x C. deliciosa* Tenora) fruits were better than the untreated fruits. However, fruits treated with MeJA (0.5 mM) showed higher overall sensory score compared to control. The sensory attributes determine the acceptability of produce in the market. The exogenous MeJA and differential temperature maintained higher quality characteristics, especially sugars, flavour and TSS, which might be on the last day of storage making it more acceptable, which can also be justified with the findings reported by Baswal et al. (2020) and Dhami et al. (2022) in mandarin fruits.

Conclusion

Overall, postharvest dip treatment of MeJA (0.5 mM) and differential temperature (2 °C and 6 °C) maintained higher firmness, physiological losses in weight, total soluble solids, TPC, ascorbic acid and AOX with higher sensorial score throughout storage period of 40 days. Further, MeJA (0.5 mM) application effectively reduced CI and acidity

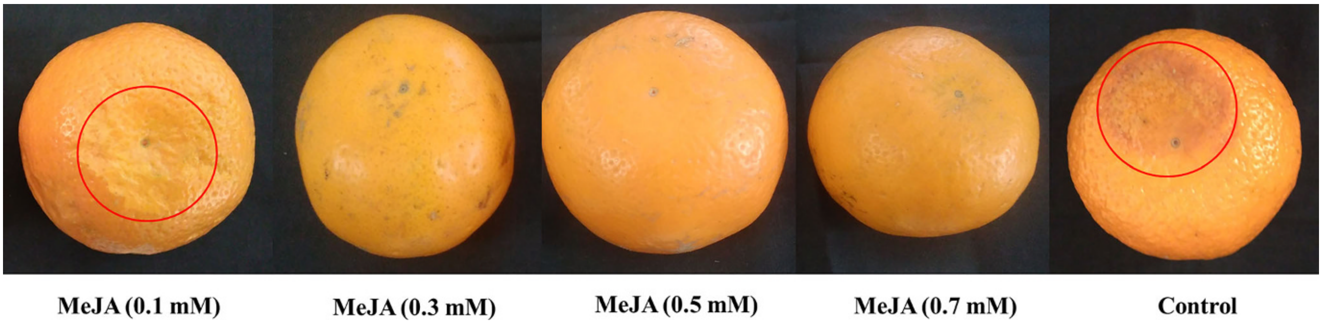

Fig. 3 Effect of methyl jasmonate (*MeJA*) and differential temperature on shelf-life of 'Kinnow' mandarin after 40 days of cold storage. The *red circle* shows the incidence of chilling injury over the fruit surface

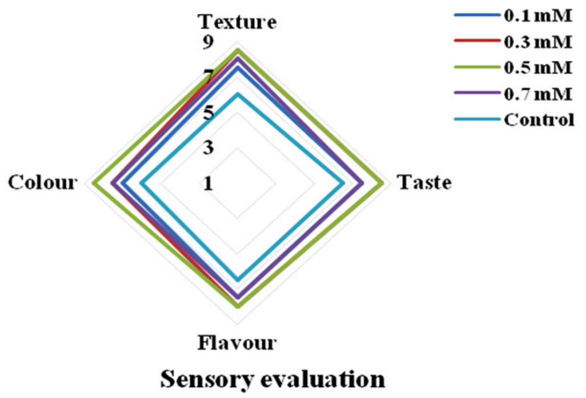

Fig. 4 Effect of methyl jasmonate and differential temperature on sensory attributes of ‘Kinnow’ mandarin during cold storage of 40 days. The data represents the mean of 10 replicates of score given on the basis of hedonic scale (1–9)

in ‘Kinnow’ (*Citrus nobilis* Lour *x C. deliciosa* Tenora) mandarin fruits during prolonged cold storage. Therefore, postharvest dip treatment of MeJA could be an effective and safe strategy for enhancing shelf-life and maintaining the quality of ‘Kinnow’ (*Citrus nobilis* Lour *x C. deliciosa* Tenora) mandarin fruits during cold storage.

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Declarations

Conflict of interest K.S. Dhami, R. Asrey, B.R. Vinod and N.K. Meena declare that they have no competing interests.

Ethical standards In the present investigation there was no human or animal participation involved. All the experiments were performed as per ethical standards.

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