



Effects of UV-C and calcium ascorbate on postharvest quality of 'Langra' mango

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ABSTRACT

Purpose: Mango is known as one of the most important fruits for its delicious taste, flavor and high nutritional properties. However, due to the perishability and short shelf life of fruit, safe treatments are needed for increasing shelf life of fruit. This experiment carried out to elucidate effects of postharvest UV-C and calcium ascorbate (CaA) on quality of mango fruit during cold storage. **Research method:** After preparing 'Langra' mango fruits were irradiated for 5 min in 5 or 10 kJ/m² UV-C or dipped for 5 min in 1.5% (CaA) or combination of calcium ascorbate and UV-C. Postharvest parameters including firmness, catalase and phenylalanine ammonia lyase activities, total phenolic content and antioxidant activities, firmness, soluble solid concentrations, ascorbic acid and sensory parameters were evaluated throughout 21 days of storage at 12°C. **Findings:** At the end of shelf life, CaA alone (1.5%), UV-C alone (5 or 10 kJ m⁻²) or combination of UV-C with CaA maintained good firmness, increased catalase activity, phenylalanine ammonia lyase activity, total phenolic content and antioxidant activity but decreased soluble solid concentrations compared with the control. Sensory parameters, such as texture, flavor, appearance and overall quality were kept acceptable for marketability with these treatments. **Research limitations:** No limitations were encountered. **Originality/Value:** Both UV-C and CaA showed potential for increasing marketability of mango with their generally recognized as safe status for consumers.

INTRODUCTION

Mango (*Mangifera indica* L.) is known as one of the most important fruits for its delicious taste, flavor and high nutritional properties, and its international trade production is increasing rapidly (Ntsoane et al., 2019). Also, mango fruit contains high levels of ascorbic acid and phenolic compounds, which prevents cardiovascular diseases and cancer (Ntsoane et al., 2019). It is cultivated in southern parts of Iran. However, due to the perishability of tropical fruits and short shelf life of fruits, safe treatments are needed for increasing shelf life of mango fruit.

Calcium is generally recognized as safe (GRAS) and can be used for decreasing physiological disorders of fruits, increasing postharvest quality of fruits and vegetables (Madani et al., 2015).

Moreover, application of innovative technologies can control chemical changes besides traditional interventions. Particularly, UV-C radiation has several advantages because it does not leave any chemical residue or damages to the microorganisms, and stimulates defense mechanisms in the product (Amiri et al., 2021). Researches have shown that UV-C is effective to maintain quality of horticultural crops like sweet cherry (Abdipour et al., 2020) and bell pepper (Castillejo et al., 2022). Moreover, it has been confirmed that calcium ascorbate (CaA) increased quality of tomato fruit (Zarea & Sayyari, 2018). Also, postharvest application of calcium increased firmness and delayed ethylene production (Gao et al., 2020). There is no report about effects of UV-C and CaA on post-harvest quality of mango. Thus, this experiment carried out to elucidate effects of postharvest UV-C and calcium ascorbate on quality of mango fruit during cold storage.

MATERIALS AND METHODS

Mature mango (*Mangifera indica* L.) cv. 'Langra' fruits greenish yellow, free from disease, injuries, and blemishes, with uniform size and maturity were obtained from Hormozgan province of Iran. After harvest, all fruits were transported to the post-harvest laboratory. Afterward, fruits were sanitized with chlorinated water (0.01%), rinsed with tap water and air-dried at ambient temperature ($25 \pm 2^\circ\text{C}$) and 75-80% relative humidity (RH) in the laboratory.

Preparation of chemicals and treatments

Calcium ascorbate (CaA) (Sigma-Aldrich, St. Louis, MO, USA) was used at 1.5% with 0.3% Tween 20 as surfactant agent. Five treatments used for mango fruits including: (T1) dipping in distilled water (control), (T2) dipping in 1.5% CaA for 5 min, (T3) irradiation with 5 kJ m^{-2} UV-C for 5 min (UV-C₁), (T4) irradiation with 10 kJ m^{-2} UV-C for 5 min (UV-C₂), (T5) irradiation in UV-C₁, then dipping in 1.5% CaA, (T6) irradiation in UV-C₂ then dipping in 1.5% CaA. After dipping, mango fruits were drained and air dried for 5 min. Fruits were irradiated with UV-C light (30 W) (TUV G30T8, 30W, Philips) at a distance of 15 cm above and below from fruits. Providing a UV-C dose measured by a digital radiometer (Model MRUR-203, Instrutherm). The treated fruits were stored at $12 \pm 1^\circ\text{C}$ for 21 days. Quality and biochemical analyses of fruits were measured at 0, 7, 14 and 21 days of storage.

Fruit firmness, soluble solids concentration and ascorbic acid content

Flesh firmness was measured by digital fruit hardness tester (STEP Systems GmbH, Germany) with a 5 mm diameter probe. The results expressed as Newton (N). Soluble solids concentration (SSC) of 10-g pulp tissues were measured by the methods of Ali et al. (2011) and results were expressed as %SSC. Ascorbic acid measurements were measured using dye

method described by Rangana (1986). Ascorbic acid content was expressed as mg 100 g⁻¹ fresh weight (FW).

Enzyme activities

The procedure for extraction and assay of catalase (CAT) was performed using the method described by Artés-Hernández et al. (2010). Results were expressed as $\mu\text{Kat kg}^{-1}\text{FW}$.

The procedure for extraction and assay of phenylalanine ammonia lyase (PAL) was carried out according to Du et al. (2012). PAL activity was calculated by measuring the increase in absorbance of samples as compared to the control samples after 1 h of incubation, quantified from a standard curve developed for t-cinnamic acid (0.00-0.06 $\mu\text{mol ml}^{-1}$), and expressed as $\mu\text{mol t-cinnamic acid per hour per g FW tissue}$.

Total phenolic content (TPC) and antioxidant activity

Total phenolic content (TPC) in mango was determined using method of Siddiq et al. (2013) and results were expressed as mg gallic acid equivalents (GAE) 100 g⁻¹ FW.

Total antioxidant activity was determined using trolox equivalent antioxidant capacity (TEAC) with ABTS radical cation decolorization assay, according to Re et al. (1999) and Siddiq et al. (2013) and results expressed as mmol Trolox equivalents (TE) 100 g⁻¹ FW.

Sensory evaluation

A panel of six trained panelists was used to evaluate the consumer acceptance of the calcium and UV-C for mango treatments during storage. Upon removal from the storage, the panelists were asked to evaluate the samples. Acceptance test were performed using a hedonic scale of 1–9, where 9 = Excellent, 7 = Good, 5 = Acceptable, 3 = Dislike, and 1 = Extreme dislike to evaluate acceptability of the treated fruits attributes, such as texture, flavor, appearance, and overall quality.

Experimental design and statistical analysis

All experiments were carried out using completely randomized design (CRD). Four replicates per treatment were used for all experiments. Data were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS) version 8.2 (SAS Institute Inc., Cary, NC, USA). The means were compared with the Duncan's Multiple Range Test (DMRT) at significance level of 0.05.

RESULTS AND DISCUSSION

Firmness, soluble solids concentration and ascorbic acid content

Results revealed that after 21 days of storage, CaA alone (1.5%), UV-C alone (5 or 10 kJ m⁻²) or combination of UV-C with CaA (T2, T3, T4, T5 and T6, respectively) maintained higher firmness than control (Table 1).

Fruit firmness is one of the most important attributes of quality for fruit. Fruit tissue becomes soft through enzyme activity of cell wall and reduces firmness. It has been shown that UV radiation prevents ethylene synthesis and halts the effective enzymes in the softening of fruits and reduces the rate of respiration which all leads to the delay in the firmness loss (Amiri et al., 2021). Moreover, maintenance of firmness in samples with calcium treatments is likely due to the fact that calcium interacts with pectic acids in the cell walls to form calcium pectate, so keeps the cell wall structure (Madani et al., 2016). Our results are comparable with (Zarea & Sayyari, 2018) who indicated that 0.5% calcium ascorbate

maintain firmness of tomato fruit, and Amiri et al. (2021) who showed that UV- C (0.5 kJ m^{-2}) maintained quality of strawberry.

Soluble solids content of mango samples increased with longer storage period regardless of the treatments (Table 1). After 14 and 21 days of storage, the increase in SSC was lower for all treatments (T2, T3, T4, T5 and T6) compared to the control samples (T1) (Table 1). The low increase in TSS values for calcium treated fruits might reflect changes in the internal atmosphere of the fruit, with a reduction in the O_2 level or an increase in the CO_2 level, which reduce the respiration rate and metabolic activity, such as the conversion of sugars into CO_2 and H_2O (Bal, 2019). The synergistic effects of CaA and UV-C irradiation caused a delay of SSC increase, likely because of inhibitory effects on enzymes' activities which are involved in the hydrolysis (Shen et al., 2013).

Ascorbic acid also decreased in all treatments during storage (Table 1). After 7, 14 and 21 days of storage, ascorbic acid was significantly higher in CaA alone (1.5%), UV-C alone (5 or 10 kJ m^{-2}) or combination of UV-C with CaA (T2, T3, T4, T5 and T6, respectively) compared to the control (T1) (Table 1). The advantageous effects of calcium in inhibiting decline of ascorbic acid during storage are partly due to the regulation of the oxidative processes in the cytosol (Mirshekari et al., 2017). High level of ascorbic acid in irradiated fruit is associated with a delay in the process of ripening and reducing respiration rates (Abdipour et al., 2019). By reducing the respiration rate, the internal oxygen concentration decreases and, conversely, the concentration of carbon dioxide increases, which leads to high levels of ascorbic acid in fruit (Abdipour et al., 2019). In addition, our results are comparable with those of (Amiri et al., 2021) who indicated a lower rate of decrement in ascorbic acid content of strawberry during storage exposed to UV-C (0.5 kJ m^{-2}).

Table 1. Flesh firmness, soluble solids concentration, and ascorbic acid of mango fruits following post-harvest applications of calcium ascorbate (CaA) and UV-C (UV-C₁= 5 kJ m^{-2} , UV-C₂= 10 kJ m^{-2}) after storage at 12°C for 7, 14 and 21 days.

Quality parameter	Treatment	Storage period (days)			
		0	7	14	21
Firmness (Newton)	T1	3.72a ^z	2.65b	1.45c	1.20b
	T2	3.82a	3.10ab	2.20b	2.10a
	T3	3.77a	3.15ab	2.23b	2.14a
	T4	3.80a	3.17ab	2.28b	2.19a
	T5	3.82a	3.57a	2.80a	2.72a
	T6	3.85a	3.55a	2.87a	2.77a
SSC (%)	T1	7.20a	10.80a	12.65a	14.35a
	T2	7.18a	8.87a	9.32b	9.47b
	T3	7.22a	8.72a	9.10b	9.22b
	T4	7.21a	8.62a	8.75b	8.80b
	T5	7.19a	8.50a	8.67b	8.87b
	T6	7.22a	8.45a	8.65b	8.75b
Ascorbic acid (mg 100 g^{-1} FW)	T1	20.02a	12.20b	9.60b	6.07b
	T2	19.62a	18.45a	13.27a	10.28a
	T3	19.37a	18.15a	13.85a	10.80a
	T4	19.57a	18.30a	14.77a	11.10a
	T5	19.47a	19.32a	14.62a	12.82a
	T6	20.80a	20.70a	14.17a	13.75a

^z Small letters in columns for each parameter show the mean comparison among treatments. Means with the same letter are not significantly different by Duncan's multiple range test at $P < 0.05$ (T1 = control, T2 = CaA, T3 = UV-C₁, T4 = UV-C₂, T5 = UV-C₁ + CaA, T6 = UV-C₂ + CaA).

Table 2. catalase (CAT) and phenylalanine ammonia lyase (PAL) activities of mango fruits following post-harvest applications of calcium ascorbate (CaA) and UV-C (UV-C₁=5 kJ m⁻², UV-C₂=10 kJ m⁻²) after storage at 12°C for 7, 14 and 21 days.

Quality parameter	Treatment	Storage period (days)			
		0	7	14	21
CAT ($\mu\text{Kat kg}^{-1}\text{FW}$)	T1	20.75a ^z	18.62b	17.35b	12.07b
	T2	20.87a	24.27a	23.27a	18.77a
	T3	21.32a	25.47a	22.75a	20.37a
	T4	22.45a	26.45a	23.40a	21.47a
	T5	20.62a	27.40a	24.32a	20.80a
	T6	21.35a	27.17a	25.25a	22.47a
PAL ($\mu\text{mol t-cinnamic acid h}^{-1}\text{g}^{-1}\text{FW}$)	T1	0.35a	0.30b	0.24b	0.22b
	T2	0.34a	0.36a	0.35a	0.31a
	T3	0.37a	0.38a	0.33a	0.30a
	T4	0.34a	0.37a	0.36a	0.31a
	T5	0.36a	0.41a	0.38a	0.34a
	T6	0.38a	0.40a	0.37a	0.33a

^z Small letters in columns for each parameter show the mean comparison among treatments. Means with the same letter are not significantly different by Duncan's multiple range test at $P < 0.05$ (T1 = control, T2 = CaA, T3 = UV-C₁, T4 = UV-C₂, T5 = UV-C₁ + CaA, T6 = UV-C₂ + CaA).

Table 3. Total phenolic content (TPC) and antioxidant activity (ABTS) of mango fruits following post-harvest applications of calcium ascorbate (CaA) and UV-C (UV-C₁=5 kJ m⁻², UV-C₂=10 kJ m⁻²) after storage at 12°C for 7, 14 and 21 days.

Quality parameter	Treatment	Storage period (days)			
		0	7	14	21
TPC (mg GAE 100 g ⁻¹ FW)	T1	73.62a ^z	65.70b	60.50b	52.2b
	T2	73.55a	75.62a	70.82a	60.42a
	T3	73.52a	77.52a	72.65a	61.42a
	T4	73.47a	78.65a	73.17a	63.60a
	T5	73.42a	79.65a	74.07a	66.25a
	T6	73.67a	81.70a	76.32a	66.10a
ABTS (mmol TE 100 g ⁻¹ FW)	T1	0.27a	0.27b	0.17b	0.21b
	T2	0.25a	0.36a	0.24a	0.28a
	T3	0.26a	0.34a	0.26a	0.30a
	T4	0.24a	0.35a	0.25a	0.32a
	T5	0.23a	0.37a	0.27a	0.33a
	T6	0.26a	0.39a	0.28a	0.34a

^z Small letters in columns for each parameter show the mean comparison among treatments. Means with the same letter are not significantly different by Duncan's multiple range test at $P < 0.05$ (T1 = control, T2 = CaA, T3 = UV-C₁, T4 = UV-C₂, T5 = UV-C₁ + CaA, T6 = UV-C₂ + CaA).

Enzymes activities

Changes in enzymes activities (CAT and PAL) over storage time are shown in Table 2. After 7, 14 and 21 days of storage CAT and PAL activity of T2, T3, T4, T5 and T6 maintained higher than control samples (Table 2). UV-C can activate antioxidant scavenger system with a consequent increasing CAT activity (Maghoumi et al., 2013). Also, Kou et al. (2014) stated that treatment of pear fruits with calcium chloride increased CAT activity.

The increase in PAL activity treated with CaA and UV-C shows that these treatments can trigger main enzymes of the secondary metabolites biosynthetic pathways in mango fruit by activating PAL. Moreover, Sun et al. (2022) reported an increase in the activity of PAL in pear fruit, after treatment with UV-C (1.08 kJ m⁻²). Also, calcium chloride (2%) enhanced PAL activity of winter jujube (Kou et al., 2021).

Total phenolic content (TPC) and antioxidant activity

The effects of calcium treatment and UV-C treatments on total phenolic content (TPC) antioxidant activity (ABTS assay) are presented in Table 3. The results showed that CaA alone (1.5%), UV-C alone (5 or 10 kJ m⁻²) or combination of UV-C with CaA (T2, T3, T4, T5 and T6, respectively) maintained higher TPC and ABTS compared to the control (T1) after 7 ,14 and 21 days in storage. Calcium application (1.5 and 2%) increased TPC and antioxidant activity of papaya fruit compared to the control (Madani et al., 2016). Also, UV-C (4.20 kJ m⁻²) increased TPC and antioxidant capacity of sweet cherry compared to the control (Zhang et al., 2021). Thus, our results suggest that CaA and UV-C treatments can stimulate increasing of phenols, in the mango fruit by activating their biosynthetic pathways and increasing PAL activity (Jacobo-Velazquez et al., 2011; Abdipour et al., 2019).

Table 4. Texture (scale = 1-9^a), flavor (scale = 1-9^a), appearance and overall quality (scale = 1-9^a) of mango fruits following post-harvest applications of calcium ascorbate (CaA) and UV-C (UV-C₁=5 kJ m⁻², UV-C₂=10 kJ m⁻² after storage at 12°C for 7, 14 and 21 days.

Quality parameter	Treatment	Storage period (days)			
		0	7	14	21
Texture ^a	T1	6.71a ^z	6.45a	4.66b	3.50b
	T2	6.63a	6.41a	6.43a	5.51a
	T3	6.53a	6.50a	6.40a	5.45a
	T4	6.50a	6.48a	6.36a	5.38a
	T5	6.45a	6.48a	6.38a	5.33a
	T6	6.61a	6.45a	6.36a	5.30a
Flavor ^a	T1	6.55a	6.28a	3.73b	3.53b
	T2	6.50a	6.25a	5.81a	5.71a
	T3	6.53a	6.23a	5.73a	5.63a
	T4	6.56a	6.26a	5.71a	5.61a
	T5	6.53a	6.20a	5.68a	5.58a
	T6	6.51a	6.26a	5.63a	5.50a
Appearance ^a	T1	7.31a	7.24a	5.65b	5.23b
	T2	7.30a	7.25a	7.11a	7.10a
	T3	7.35a	7.23a	7.13a	7.05a
	T4	7.36a	7.25a	7.03a	7.03a
	T5	7.38a	7.26a	7.20a	7.13a
	T6	7.33a	7.23a	7.21a	7.15a
Overall quality ^a	T1	7.41a	7.13a	5.75b	5.13b
	T2	7.43a	7.15a	7.06a	7.08a
	T3	7.46a	7.06a	6.98a	6.83a
	T4	7.40a	7.01a	6.83a	6.76a
	T5	7.45a	7.03a	6.81a	6.71a
	T6	7.48a	7.11a	6.70a	6.68a

^z Small letters in columns for each parameter show the mean comparison among treatments. Means with the same letter are not significantly different by Duncan's multiple range test at $P < 0.05$ (T1 = control, T2 = CaA, T3 = UV-C₁, T4 = UV-C₂, T5 = UV-C₁ + CaA, T6 = UV-C₂ + CaA).^a Hedonic scale of 1–9, where 9 = Excellent, 7 = Good, 5 = Acceptable, 3 = Dislike, and 1 = Extreme dislike, to evaluate acceptability of the treated fruit' attributes (texture, flavor, appearance and overall quality).

Sensory evaluation

Sensory evaluation of fruit (texture, flavor, appearance and overall quality) was higher in T2, T3, T4, T5, and T6 after 14 and 21 days of storage, compared to the control fruits (T1) (Table 4). Keeping overall quality of fruit is a major issue because it noticeably affected during long time storage. Our findings are consistent with results of Abdipour et al. (2019) in peach which a higher sensory score for UV-C treated sample (28.8 kJ m^{-2}) was observed in comparison to the control. The higher acceptability of mango fruit samples with calcium or UV-C treatments was likely due to the delay of the biochemical processes which cause delaying the processes responsible for decaying, solubilization of pectic substance and loss of volatiles. Therefore, higher firmness and sensory perception of samples treated with CaA and UV-C caused higher acceptability for the market. In addition, the formation of cross-linking between calcium ion and carboxyl groups in pectin reduced amount of free calcium ion responsible for the unpleasant taste and overall quality (Nguyen et al., 2020). Moreover, these results are comparable with those of Hussain et al. (2012) who found that 2% calcium chloride and gamma irradiation (0.4 kGy) increased the overall quality of apple fruit.

CONCLUSION

Experiment showed that after 21 days of storage, CaA alone (1.5%), UV-C alone (5 or 10 kJ m^{-2}) or combination of UV-C with CaA maintained good firmness, increased catalase activity, phenylalanine ammonia lyase activity, total phenolic content and antioxidant activity but decreased soluble solid concentrations compared with the control. Sensory parameters, such as texture, flavor appearance and overall quality were kept acceptable for marketability with these treatments. These treatments also increased nutritional value of mango.

Conflict of interest

The authors have no conflict of interest to report.

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