ANSF® APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
16(2), 794 - 804 (2024)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Response of melatonin on postharvest qualities and shelf life of pineapple cv. Kew at ambient storage

Debashis Mandal*
Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl (Mizoram), India
Nchumbeni Ennio
Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl (Mizoram), India
Noel Lalhruaitluangi
Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl (Mizoram), India
Lalrinchhani
Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizaw (Mizoram), India
Agnes Vanlalnghaki Fanai
Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl (Mizoram), India

*Corresponding author. E-mail: debashismandal1982@gmail.com

Article Info
https://doi.org/10.31018/jans.v16i2.5562
Received: March 14, 2024
Revised: May 27, 2024
Accepted: June 02, 2024

How to Cite
Mandal, D. *et al.* (2024). Response of melatonin on postharvest qualities and shelf life of pineapple cv. Kew at ambient storage. *Journal of Applied and Natural Science*, 16(2), 794 - 804. https://doi.org/10.31018/jans.v16i2.5562

Abstract
Melatonin is a pleiotropic molecule which plays a pivotal role in extending shelf life and maintaining the postharvest quality of fruit. Pineapple fruits harvested at different stages of maturity had marked variations in physico-biochemical qualities and shelf life during storage. The present study aimed to determine the potential effectiveness of different concentrations of postharvest melatonin applications on pineapple cv. Kew fruit in ambient storage. Different concentrations of melatonin (MT) solution viz. T_1: MT at 0.25mM, T_2: MT at 0.5 mM, T_3: MT at 1 mM, T_4: MT at 2 mM, T_5: MT at 4 mM and T_6: MT at 8 mM were used for the study and compared with T_7: untreated fruits (control). At 20 days after storage, fruits dipped in 8 mM melatonin resulted in lowest physiological weight loss (11.84%), fruit decay (13.33%), decrease in fruit length (3.29%) and diameter (3.42%), juice content (58.27%), titratable acidity (0.91%), flesh translucency (2.0) and crown condition (2.6) these resulted in the decrease with the increase in concentration of melatonin. Maximum shelf life (23.33 days), fruit firmness (39.24 Ncm^2), TSS (10.3ºBrix), total sugar (10.10%), reducing sugar (8.85%), TSS: Acid ratio (11.30), ascorbic acid (19.3 mg $100g^{-1}$), total Carbohydrate (10.08%), total phenol (35.64mg $100g^{-1}$) and antioxidant activity (48.14%) increased depending on increment in melatonin concentration as compared to control. Results of the study showed that Melatonin @ 8mM has a marked influence in extending the shelf life while maintaining the physico-chemical quality of stored pineapple and thus can be a good option in using the technique for commercial shelf life extension in ambient conditions.

Keywords: Biochemicals, Melatonin, Physico-chemical changes, Pineapple, Quality, Shelf life

INTRODUCTION

Pineapple (*Ananas comosus* L.) is an important fruit in the Bromaliaceae and an excellent source of vitamins like A, B and C and minerals viz. Fe, P and Ca. Besides, it is a good source of health-promoting plant chemicals. Bromelain is a protein digestive enzyme found in the pineapple plant's fruit and stem (Kamol *et al.*, 2014). Currently (2020-2021) in India, pineapple is produced 1774 thousand MT from 107 thousand hectares (Anonymous 2021). India ranked 6^{th} with a share of about 8% of world production. More than 40% of the total production of pineapple is contributed by North-east regions of the country (Anonymous 2018), with 90-95% of its produce being organic (Sema *et al.*, 2011).
Pineapple fruit showed ample variation in fruit physico-

chemical qualities and storage when harvested at different maturity stages (Dhar *et al*., 2008). Harvesting pineapple fruits at correct maturity stage is crucial as it is non-climacteric in nature and after harvest, its eating quality does not enhance, nor does its sugar content increase. Therefore, to be acceptable to the intended market pineapple fruits should be picked at optimum maturity and ripeness stage (Joy and Rajuva, 2016). Pineapple fruit, being a perishable crop, needs proper postharvest handling to ensure the fruit's quality. India alone is estimated to experience postharvest losses of about 32% from total production, where a major loss of 9.63% was due to over-ripening, followed by 8.96% of mechanical damages. The loss due to spoilage was 5.01% followed by 4.85% loss due to immature/ unmarketable sizes, 1.55% loss contributed by storage conditions and 2.12% due to other factors (Ningombam *et al*., 2019). To reduce postharvest losses in pineapples, several postharvest handling practices can be followed (Hossain and Bepary, 2015). Different chemical reagents can be used to enhance the shelf life of fruits and vegetables (Kuang *et al*., 2008; Wang *et al*., 2012).

Melatonin is a multifunctional signaling molecule chemically denoted as N-acetyl-5-methoxytryptamine that is distributed far and wide in various plant species (Tan *et al*., 2002) and an endogenous indoleamine, marked ability of scavenging free radicals and an antioxidant (Reiter *et al*., 1999). Different plant physiological activities are marked influenced by melatonin, starting from plant growth, root development, flowering, fruit development and ripening, plants response to biotic and abiotic stress and up to senescence, etc. Melatonin, a safe and non-toxic substance, is profusely under use in maintaining postharvest qualities and shelf life of fruits and vegetables apart from its uses in crop production (Fan *et al*., 2022). Recent reports suggested that melatonin regulates various physiological processes like fruit ripening and prevents postharvest senescence of fruits like bananas, peaches, grapes, strawberries and tomatoes (Mukherjee, 2019). Besides, melatonin improves postharvest ripening and quality of different climacteric as well as non-climacteric fruits (Sun *et al*., 2015). Fruits like apples, bananas, cherries, grapes, pineapples, tomatoes and strawberries are commonly used in the healthy human diet and proves to be a good source of natural melatonin (Reiter *et al*., 2005; Sae-Teaw *et al*., 2013). Melatonin, when used exogenously tested to be an effective postharvest tool which encourages ripening and improves postharvest qualities of tomatoes, delays senescence and increases chilling tolerance of stored peach (Cao *et al*., 2016; Gao *et al*., 2016), attenuating postharvest decay and maintaining nutritional properties of stored strawberry (Liu *et al*., 2018). It has been proven that melatonin applied exogenously delayed the postharvest ripening of fruits like apples (Onik *et al*., 2021), sweet cherries (Tijero *et al*., 2019), bananas (Li *et al*., 2019; Hu *et al*., 2017), pears (Liu *et al*., 2019), peaches (Gao *et al*., 2016) and mangoes (Liu *et al*., 2020). Studies have reported incidence of decay has been reduced in several fruits during postharvest storage, which occurs with exogenous melatonin treatment, including litchis (Zhang *et al*., 2021), strawberries (Aghdam and Fard, 2017), kiwifruits (Hu *et al*., 2018) and peaches (Gao *et al*., 2016). Currently the most common postharvest handling method is soaking or spraying melatonin solution (Ze *et al*., 2021). However, there is scanty information on postharvest use of melatonin in pineapple. Therefore, the present investigation was conducted to study the influence of melatonin on the postharvest qualities and shelf life of pineapple cv. Kew at ambient storage.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in Postharvest Laboratory, Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, situated at Tanhril- Aizawl, Mizoram.

Fruit material and melatonin treatment

Fully matured green fruits grown in open fields at Ailawng, Reiek block of Mamit district of Mizoram were chosen for samples. Freshly harvested pineapple cv. Kew fruits were thoroughly washed under running water and air drying at room temperature. For each treatment, fruits were tagged and subjected to six melatonin (MT) treatments by dipping in viz., T_1: MT at 0.25 mM, T_2: MT at 0.5 mM, T_3: MT at 1 mM, T_4: MT at 2 mM, T_5: MT at 4 mM, T_6: MT at 8 mM and T_7: Control for 60 minutes followed by air drying in ambient condition. Then all the melatonin-treated pineapples were kept on an open shelf and covered with a perforated net for the duration of storage at an ambient temperature range of 20 to 25 °C and relative humidity of 65 to 85%. The physical and biochemical parameters of the fruits were recorded each 5 days after storage (DAS).

Fruit peel/skin and flesh colour

Fruits for each treatment in pineapple for skin and flesh colour were measured with a digital handheld colour meter and expressed as L*, a*, b* (as per Commission International d' Eclairage,1976) where L* value for bright dark scale, a* value is positive for red whereas negative for green and b* value is positive for yellow while negative for blue colour.

Physiological weight loss

At a 5-day interval, fruit weighed was measured using a digital electronic balance. The following equation was used for calculating percentage weight loss:-

Percentage weight loss at n^{th} day = (Fruit weight at 0 day- fruit weight at n^{th} day) / Fruit weight at 0 day × 100 Eq. 1

Percent decrease in fruit length and diameter

The length and diameter of fruits for each treatment were measured using a digital slide caliper at 5 days intervals. The following equation was used to calculate per cent decrease in fruit length and diameter:-

Percent decrease (n^{th} day)= (Initial length / diameter at 0 day – length/diameter at n^{th} day) × 100 / Initial length/ diameter at 0 day Eq.2

Juice percentage (%)

Juice percentage of fruit was calculated with the help of the given formula:

Percentage of juice in fruit pulp = (Weight of fruit juice × 100) / Weight of fruit pulp Eq.3

Fruit firmness, scoring for crown condition and flesh translucency

The texture/firmness of pineapple fruit samples was recorded using a handheld digital penetrometer device. Crown condition, flesh translucency, etc. visual quality indices were recorded per the standard procedure (Mandal *et al.*, 2015).

Scores for crown condition and flesh translucency were as follows:

Crown condition

Good, fresh and green: Score 1; Good with slightly yellow at tips: Score 2; Moderate, dry tips and yellowing: Score 3; Bad, dry tips and more yellowing: Score 4; Severe yellowing: Score 5

Flesh translucency

100% opaque: Score 1; Opaque with slight translucent (less than 50%): Score 2; Opaque with moderate translucent (more than 50%): Score 3; 100% translucent: Score 4

Biochemical parameters

Fruit juice was extracted by cutting the pineapple flesh, crushing it in mortar and pestle, and then strained with the muslin cloth. Fresh extracted juice was used to estimate total soluble solids (TSS) and was expressed in degree brix after temperature correction at 20^0C. Fresh juice's total and reducing sugar content was estimated using Fehling's reagents (A&B) through the copper reduction method and methylene blue as an indicator (AOAC, 1990). Titratble acidity of the freshly extracted pineapple juice was measured by titration against sodium hydroxide (N/10) and phenolphthalein indicator (AOAC, 1990). Fruit ascorbic acid content (Vitamin -C) was estimated by titration method using 2,6 dichlorophenol indophenol dye (AOAC, 1990; Ranganna, 1997), and Folin-Ciocalteau method was followed to determine total phenols by using 80% ethanol. Folin-Ciocalteau reagent and 20% sodium carbonate and a digital Spectrophotometer at 650nm were used for recording the absorbance (Sadasivam and Manickam, 1996). For estimation of total carbohydrates, the Anthrone method was followed using Anthrone reagent and HCl and absorbance at 630 nm was recorded with a digital Spectrophotometer (Sadasivam and Manickam, 1996). Antioxidant activity of the fruit juice was determined using methanol and DPPH following DPPH assay and absorbance was measured using a digital spectrophotometer at 516 nm (Pekkarinen *et al.*, 1999). The percentage of antiradical activity was calculated by following the equation:

% Antiradical activity = Absorbance (Control) – Absorbance (Sample) / Absorbance (Control) × 100 Eq. 4

Decay percentage and shelf life

Visual observations were done to determine the decay percentage of stored pineapple. The decayed fruits were divided by the total number of fruits to calculate the decay percentage of stored pineapple fruits (Pila *et al*., 2010). Visual observation of spoilage, fruit decay and physico-chemical parameters were considered along with days count from harvest to days with the highest visual appearance and edible marketable quality for calculating the shelf life (days) of the stored pineapple fruits under different melatonin treatments along with control (Pila et al., 2010; Mandal and Vanlalawmpuia, 2020).

Statistical analysis

Data analysis was done using SPSS software version 22 for statistical inference by following the method of Complete Randomized Design (CRD) (Gomez and Gomez, 1984).

RESULTS

Physiological weight loss

Physiological weight loss of pineapple samples varied significantly due to the different postharvest treatments at room temperature. Regardless of the treatments, weight loss in pineapple fruits increased for 20 days storage. At 20 days after storage (DAS), among all the treatments, the highest physiological weight loss was observed in fruits at control, having 28.71% and the fruits treated with 8.0 mM (T_6) melatonin had the least physiological weight loss of 11.84%. Fruits treated with melatonin resulted in weight loss significantly lower than fruits in control (Table 1).

Percent decrease in length and diameter

The length and diameter of pineapple fruits gradually decreased during ambient storage. Fruit length and diameter decreased most in control fruits with 13.05%

and 11.86% decreases at 20 DAS, respectively (Table 1). At 20 DAS, fruits treated with 8.0 mM melatonin (T_6) had the least decline in length and diameter, with 3.29% and 3.42%, respectively.

Fruit firmness

Loss in firmness was significantly reduced by melatonin during ambient storage when compared to fruits at control. The fruits at control began to lose firmness and had the lowest firmness with a decreasing trend in values of 38.69 N, 31.32 N, 28.76 N, and 20.52 N for 5, 10, 15 and 20 DAS (Table 2). Meanwhile fruits treated with 8.0 mM melatonin (T_6) recorded highest firmness in decreasing order of 55.53 N, 45.73 N, 41.47 N, and 39.24 N at 5, 10, 15 and 20 DAS.

Juice percentage

Pineapple juice content also decreased along with physiological changes such as fruit weight, length and firmness (Table 2). The juice content of the fruit kept increasing during the entire storage period. Control (T7) fruits recorded the highest juice content with 69.13%, 74.58%, 83.52% and 89.02% at 5, 10, 15 and 20 DAS. Fruits treated with 8.0 mM melatonin (T_6) at 5, 10, 15 and 20 DAS had the least juice content with an increasing order of 51.88 %, 52.78%, 54.69 % and 58.27%.

Fruit skin and flesh colour

The skin and flesh colour of pineapple fruits were measured at 20 DAS. The final result was illustrated using a calorimeter and it manifested that stored pineapple fruits when treated with Melatonin at 0.25 mM (T_1) have the maximum peel colour (dark orange; L:42.55, a: 48.88, b: 36.71) while full orange colour can be found in fruits at control (T_7) (L: 44.43, a: 43.55, b: 43.77). Fruits at T_6, i.e. treated with melatonin at 8.0mM remained green to turning orange colour (L:47.95, a:5.17, b:26.37) after 20 days of storage (Table 3). In case of flesh colour, fruits at control (T_7) had maximum flesh colour accumulation (deep golden yellow, L: 38.56, a: 3.38, b: 35.87) whereas, fruits treated with Melatonin at 8.0 mM (T_6) had white to creamy yellow colour (L:62.41, a:-1.91, b:28.29).

Flesh translucency and crown condition

At 20 DAS, fruits at control had maximum flesh translucency with increasing scores of 4.0 fruits treated with 8.0 mM (T_6) melatonin had the lowest flesh translucency with 2.0 at 20 DAS (Fig 1). Untreated fruits, i.e. control (T_7) showed the highest crown condition score at 20 DAS with an average score of 5.0 and 8.0 mM melatonin-treated (T_6) fruits had the least change in pineapple crown condition with a score of 2.6 respectively (Fig. 2).

Table 1. Effect of treatment of melatonin on weight loss, decrease in fruit length and fruit diameter of pineapple

Treatments	Physiological Weight Loss (%)				Decrease in fruit length (%)				Decrease in fruit breadth (%)			
	DAS											
	5	10	15	20	5	10	15	20	5	10	15	20
T_1: MT0.25mM	5.43	12.63	13.75	16.46	3.98	4.93	6.86	10.75	3.08	4.46	6.42	9.16
T_2: MT0.50mM	5.26	11.36	12.84	14.82	3.16	4.07	6.14	8.68	2.96	4.12	5.38	7.58
T_3: MT1.0mM	4.42	10.47	12.33	14.13	2.51	3.18	5.08	7.42	2.13	3.64	5.13	6.47
T_4: MT2.0mM	3.17	9.45	11.71	13.92	1.89	2.32	3.96	5.06	1.78	3.16	4.32	4.82
T_5: MT4.0mM	2.78	9.38	10.87	12.77	1.43	2.03	3.17	4.12	1.56	2.28	3.49	3.86
T_6: MT8.0mM	2.25	8.24	9.72	11.84	0.98	1.15	2.47	3.29	1.12	1.75	2.48	3.42
T_7: Control	8.13	13.42	21.56	28.71	5.32	6.78	7.93	13.05	5.18	6.56	8.49	11.86
SEm±	0.69	0.75	0.83	0.79	0.57	0.62	0.69	0.73	0.68	0.73	0.69	0.81
CD at 5%	1.21	1.31	1.45	1.36	0.99	1.08	1.21	1.28	1.19	1.28	1.23	1.42

Melatonin=MT, Days after storage=DAS

Table 2. Effect of treatment of melatonin on fruit firmness and juice content of stored pineapple

Treatments	Firmness (N cm^{-2})				Juice Content (%)			
	DAS							
	5	**10**	**15**	**20**	**5**	**10**	**15**	**20**
T_1: MT0.25mM	44.43	36.64	34.32	30.22	57.69	64.55	69.78	74.57
T_2: MT0.50mM	48.77	37.38	35.48	31.9	56.34	60.35	66.38	69.38
T_3: MT1.0mM	48.97	38.81	36.52	33.76	55.71	58.47	63.64	67.22
T_4: MT2.0mM	52.27	39.64	37.16	35.51	54.12	57.69	59.23	62.51
T_5: MT4.0mM	53.68	41.86	37.97	38.42	53.89	54.52	57.54	59.52
T_6: MT8.0mM	55.53	45.73	41.47	39.24	51.88	52.78	54.69	58.27
T_7: Control	38.67	31.32	28.76	20.52	69.13	74.58	83.52	89.02
SEm±	1.05	1.18	1.25	1.21	1.12	1.24	1.20	1.18
CD at 5%	1.84	2.06	2.19	2.11	1.96	2.17	2.10	2.06

Melatonin=MT, Days after storage=DAS

Table 3. Effect of treatment of melatonin on peel and flesh colour of stored pineapple

Treatments	Peel colour values at 20 DAS			Flesh colour values at 20 DAS		
	L	A	b	L	a	b
T_1: MT0.25mM	42.55	48.88	36.71	61.99	4.47	33.87
T_2: MT0.50mM	50.32	38.24	43.64	63.78	4.32	25.49
T_3: MT1.0mM	54.84	31.81	27.22	70.73	3.73	19.87
T_4: MT2.0mM	59.97	31.94	30.84	72.18	0.61	14.21
T_5: MT4.0mM	71.92	15.84	27.37	62.47	-3.14	22.88
T_6: MT8.0mM	47.95	5.17	26.37	62.41	-1.91	28.29
T_7: Control	44.43	43.55	43.77	38.56	3.38	35.87
SEm±	-	-	-	-	-	-
CD at 5%	-	-	-	-	-	-

Melatonin=MT, Days after storage=DAS

TSS, titratable acidity and TSS: acid ratio

The highest TSS content at 20 DAS was recorded in fruit treated with 8.0 mM melatonin (T_6) having 10.34° Brix. The least TSS content recorded was in control (T_7) with 5.75° Brix at 20 DAS respectively (Table 4). The current study also revealed that titratable acidity increased during storage period in all the treatments. The highest titratable acidity at 5, 10, 15 and 20 DAS was recorded in control (T_7) having 1.02%, 1.15%, 1.23% and 1.41% respectively. The lowest titratable acidity at 5, 10, 15 and 20 DAS was recorded in samples treated with 8.0mM melatonin (T_6) having 0.77%, 0.83%, 0.86% and 0.91% respectively (Table 4). The highest TSS:Acid ratio was recorded in 8.0 mM melatonin (T_6) treated fruits 11.36 at 20 DAS and the lowest TSS: Acid ratio at 20 DAS was recorded in control (T_7) with 4.08 (Table 4).

Total and reducing sugar

Total sugar decreased with storage, except for fruits treated with 4.0 mM (T_5) and 8.0 mM (T_6) at 10 DAS, which showed a slight increase at 12.58% and 12.82%, respectively. The highest total sugar content at 20 DAS was recorded in 8.0 mM melatonin-treated (T_6) fruits, which had 10.18%, and the least sugar content was found in the control (T_7) group, which had 4.79%, respectively. At 20 DAS, the highest reducing sugar was recorded in 8.0 mM melatonin (T_6) treated fruits with 9.15% and the least reducing sugar at control (T_7) with 3.82%, respectively (Table 5).

Ascorbic acid content

The highest ascorbic acid at 5, 10, 15 and 20 DAS was observed in 8.0 mM melatonin treatment (T_6) having 28.36 mg/100g, 25.56 mg/100g, 23.45 mg/100g and 19.32 mg/100g, respectively, whereas the least ascorbic acid was recorded at 5, 10, 15 and 20 DAS in control (T_7) with 16.42 mg/100g,13.68 mg/100 g,10.78 mg/100 g and 6.78 mg/ 100 g, respectively (Table 5).

Total carbohydrate, phenol content and antioxidant activity

Total carbohydrate content decreased with storage, and the highest carbohydrate content at 20 DAS was observed in 8.0 mM melatonin-treated (T6) fruits, which was 10.08%. The least carbohydrate content was recorded at control (T_7) which was 3.12%. The phenol content in stored pineapple kept decreasing during the entire storage period. At 20 DAS, samples treated with 8.0 mM melatonin (T_6) showed the highest phenol content of 35.64 mg/100g, while fruits at control (T_7) had the least phenol content of 4.28 mg/100g. The highest antioxidant activity at 20 DAS was observed in samples treated with 8.0 mM melatonin (T_6) having 48.14% and the least antioxidant activity was recorded in fruits at control (T_7) having 11.28% (Table 6).

Fruit decay and shelf life

The decay percentage in the stored fruits decreased with increase in the concentration of melatonin treatment. At 20 DAS, fruits at control (T_7) deteriorated the

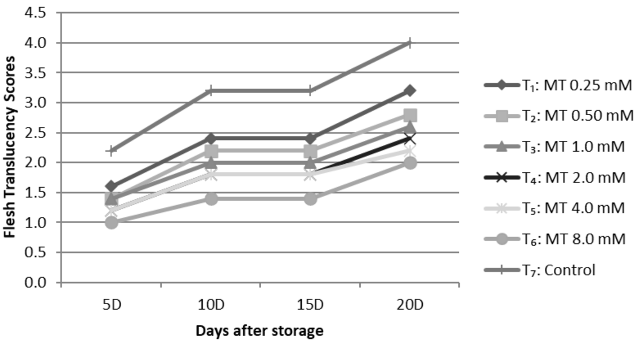

Fig. 1. *Effect of treatment of melatonin on flesh translucency scores of stored pineapples*

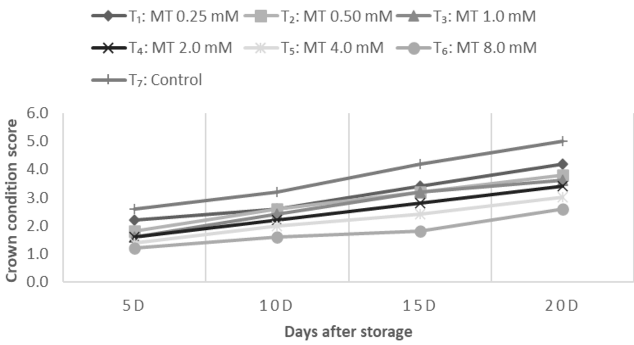

Fig. 2. *Effect of treatment of melatonin on crown condition scores of stored pineapples*

most, having 73.33%, and the lowest decay percentage was found in fruits treated with 8.0 mM melatonin (T_6), which had 13.33 %. Based on the experiment results, samples treated with 8.0 mM melatonin (T_6) have the longest shelf life of 23.33 days followed by 4.0mM melatonin treated (T_5) fruits having 21.13 days. Fruits at control (T_7) had the shortest shelf life of 12.87 days (Fig. 3).

DISCUSSION

The present study found that physiological weight loss of the pineapple gradually increased with the duration of storage. Changes in the physiological weight of fruits after harvest generally happen due to the loss of moisture through respiration and transpiration (Lufu *t al*., 2019). However, the present study observed that the pineapple fruits treated with melatonin had considerably lower physiological weight loss than the control. Fruits treated with melatonin 8.0 mM (T_6) had the least physiological weight loss (Table 1). Similar observation was reported in the case of storage of mango (Rastegar *et al*., 2020), peach (Gao *et al*., 2016) and strawberry (Liu *et al*., 2018) when treated with melatonin exogenously. Melatonin may have maintained higher turgor pressure in cells, which caused the lower weight loss (Liu *et al*., 2018). In the present study, melatonin-treated pineapple fruits had a low percentage decrease in fruit length and diameter compared to the control (Table 1), signifying less shrinkage during storage and thus having higher fruit firmness than the control (Table 2). Pineapple fruits treated with melatonin @ 8.0 mM (T_6) had maximum fruit firmness at 20 DAS. Li *et al*. (2018) opined that improvement in water-retaining properties by decreasing the permeability of the cellular membrane had become responsible for the maintenance of fruit firmness. Researchers found enhanced activity of pectinmethylesterase, β-galactosidase and polygalacturonase in postharvest softening of pineapple fruits and it was thought to decrease the fruit quality (Remon *et al*., 2003). Earlier reports showed that melatonin (MT) treatment in peaches increased firmness by increasing the expression of various important genes involved in cell wall disassembly during storage (Gao *et al*., 2016).

The present study revealed that MT-treated pineapple fruits resulted in better skin and flesh colour retention than the control group (Table 3). Chlorophyll degradation of skin was delayed in MT treated pineapple fruits

Table 4. Effect of treatment of melatonin on total soluble solids (TSS), acidity and TSS:Acid ratio of stored pineapple

Treatments	Total Soluble Solids (TSS) (^{0}Brix)				Titrable acidity (%)				TSS: acid Ratio			
	DAS											
	5	10	15	20	5	10	15	20	5	10	15	20
T_1:MT0.25mM	15.84	12.62	8.75	7.58	0.96	1.04	1.09	1.12	16.50	12.13	8.03	6.77
T_2:MT0.50mM	15.32	13.46	9.28	8.16	0.92	0.98	1.01	1.09	16.65	13.73	9.19	7.49
T_3:MT1.0mM	14.84	13.54	9.56	8.68	0.87	0.92	0.97	1.02	17.06	14.72	9.86	8.51
T_4:MT2.0mM	13.75	14.08	10.52	8.92	0.85	0.89	0.92	0.98	16.18	15.82	11.43	9.10
T_5:MT4.0mM	13.26	14.38	11.34	9.18	0.82	0.85	0.89	0.96	16.17	16.92	12.74	9.56
T_6:MT8.0mM	12.56	14.62	11.75	10.34	0.77	0.83	0.86	0.91	16.31	17.61	13.66	11.36
T_7:Control	16.75	10.34	7.45	5.75	1.02	1.15	1.23	1.41	16.42	8.99	6.06	4.08
SEm±	0.66	0.65	0.57	0.63	0.01	0.03	0.02	0.03	0.18	0.25	0.47	0.23
CD at 5%	1.15	1.13	1.01	1.11	0.02	0.05	0.04	0.06	0.32	0.44	0.82	0.40

Melatonin=MT, Days after storage=DAS

Table 5. Effect of treatment of melatonin on total sugar, reducing sugar and ascorbic acid content of stored pineapple

Treatments	Total sugar (%)				Reducing sugar (%)				Ascorbic Acid (mg 100g^{-1})			
	DAS											
	5	10	15	20	5	10	15	20	5	10	15	20
T_1:MT0.25mM	13.96	10.78	8.13	7.09	11.87	8.21	6.38	5.68	18.78	16.68	12.96	11.75
T_2:MT0.50mM	13.85	11.35	8.67	7.58	11.72	8.94	6.94	6.24	20.18	19.52	15.58	13.26
T_3:MT1.0mM	13.72	11.26	8.97	8.13	11.05	9.52	7.12	7.08	22.62	19.98	16.81	14.41
T_4:MT2.0mM	12.58	11.92	9.54	8.56	10.38	9.86	8.06	7.43	23.38	20.76	18.37	14.82
T_5:MT4.0mM	12.32	12.58	10.28	8.79	10.16	11.04	8.98	7.62	26.57	23.18	20.86	16.46
T_6:MT8.0mM	11.32	12.82	10.79	10.18	9.78	10.87	9.15	8.85	28.36	25.56	23.45	19.32
T_7:Control	14.25	9.38	6.12	4.79	12.48	7.56	5.32	3.82	16.42	13.68	10.78	6.78
SEm±	0.59	0.38	0.25	0.19	0.23	0.28	0.24	0.31	0.78	1.03	0.75	0.93
CD at 5%	1.05	0.67	0.44	0.33	0.40	0.50	0.43	0.55	1.36	1.79	1.31	1.64

Melatonin=MT, Days after storage=DAS

which caused delayed accumulation in the characteristic yellow colour development of the skin while maintained the white colour of flesh to be marked as delayed senescence. MT treatment affects chlorophyll content in rice and broccoli, delaying natural senescence (Liang *et al*., 2015; Ba *et al*., 2022). MT treatment may have retarded the colour change internally in the flesh of pineapple, which was associated with flesh yellowing and carotenoid synthesis and showed maintenance of L* and hue* values (Wu *et al*., 2020). Application of melatonin also delays color evolution in litchi, strawberry and broccoli (Liu *et al.*, 2018; Wu *et al*., 2020; Zhang *et al*., 2018). Cryptoxanthin, a significant carotenoid present in pineapple flesh, is responsible for the delay in the increase of carotenoids, which led to whiter and paler flesh showing reduction in carotenoid biosynthesis as a result of MT application (Paull, 1993).

Pineapple fruits exhibited water soaking symptoms, which resulted in higher flesh translucency in the later part of the storage (Fig.1). Electrolyte leakage is reported to be the reason for higher flesh translucency in pineapple when stored at ambient temperature (Chen and Paull, 2001). However, in the present study, it was found that fruits treated with MT 4 to 8 mM had lower score for flesh translucency (Fig.1). Badiche-El Hilali *et al*. (2023) similarly observed that MT treatment caused reduction of electrolyte leakage dose dependent manner which may have caused lower flesh translucency. Juice content of the stored pineapple was increased with period of storage may be because of higher electrolyte leakage and senescence (Chen and Paull, 2001). At 20DAS, juice percentage was recorded highest in control (T_7) compared with fruits treated with MT @ 8.0 mM (T_6) (Table 2). MT was reported to retard senescence (Sharafi *et al*., 2021; Guillen *et al*., 2022) which may have caused lower juice percentage at MT treated fruits in the present study.

Present study manifested that MT (4-8 mM) treated pineapple fruits had higher TSS than control (Table 3). Treatment of peaches with a solution of 100µM melatonin for 2 h increased TSS value over control (Cao *et al*., 2016). Loss of soluble solids during storage in fresh cut pitaya fruits could be delayed by melatonin treatment (Ba *et al*., 2022). Besides, it was noted that level of titratable acidity in stored pineapple was efficiently maintained in MT @8.0mM (T_6) treated fruits (Table 4). Wang *et al.* (2022) observed that MT treated papaya

Table 6. Effect of treatment of melatonin on total carbohydrates, total phenol and antioxidant activity of stored pineapple

Treatments	Total carbohydrates (%)				Total phenol (mg $100g^{-1}$)				Antioxidant activity (% Inhibition DPPH)
	DAS								
	5	10	15	20	5	10	15	20	20
T_1: MT0.25mM	13.08	9.67	7.68	6.38	37.15	25.83	17.82	10.52	24.75
T_2: MT0.50mM	12.42	9.82	8.16	7.56	39.42	28.75	21.54	14.74	27.32
T_3: MT1.0mM	11.85	10.79	8.71	7.82	45.64	35.41	25.28	19.38	31.46
T_4: MT2.0mM	11.68	11.42	9.32	8.13	57.15	46.72	36.54	23.47	36.34
T_5: MT4.0mM	11.72	11.82	10.54	8.56	66.32	55.18	42.29	28.71	42.02
T_6: MT8.0mM	12.16	12.56	11.16	10.08	72.95	64.92	53.47	35.64	48.14
T_7: Control	13.18	8.92	4.87	3.12	21.02	15.34	8.31	4.23	11.28
SEm±	0.21	0.27	0.25	0.23	1.29	1.28	1.18	1.09	1.27
CD at 5%	0.37	0.47	0.44	0.41	2.26	2.25	2.07	1.91	2.23

*Melatonin=MT, Days after storage=DAS

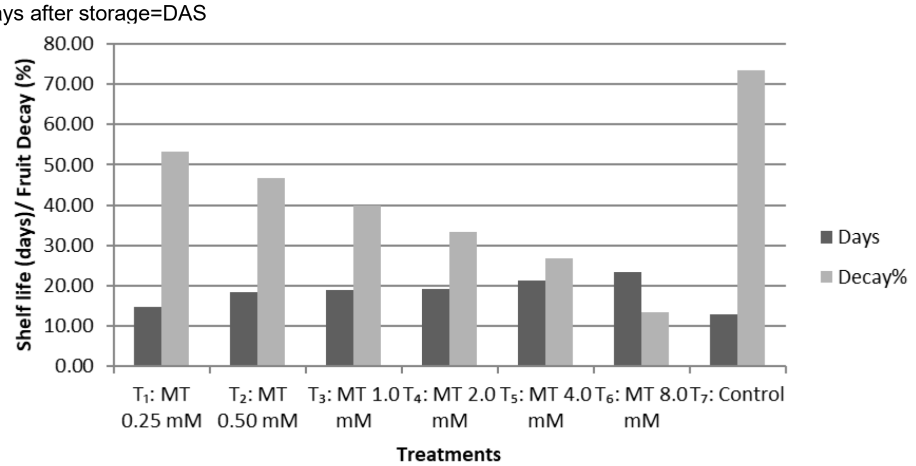

Fig. 3. *Effect of treatment of melatonin on shelf life and fruit decay percentage of stored pineapples*

fruits had better retention of titratable acidity than control. The present study revealed that total sugar and carbohydrate content drastically reduced during storage (Table 5,6). However, fruits treated with MT @ 8.0mM (T_6) maintained high sugar content even after 20 DAS. Long-term storage of pineapple results in a drop in total sugar due to fruit senescence (Hong *et al*., 2013). Decrease in sugar content during longer storage periods may be due to sugar utilization by bacteria or fungus (Sayka *et al*., 2014). MT treated fruits was reported to have better retention of total sugar during storage (Wang *et al.,* 2022).

Storage of pineapple in ambient conditions caused the loss in ascorbic acid content across the treatments (Table 5). Fruits treated with MT @ 8.0mM (T_6) had the highest amount of ascorbic acid at 20 DAS compared with control. Due to conversion of L-ascorbic acid into dehydro ascorbic acid caused by ascorbic acid oxidase shows decline in ascorbic acid of the fruit at the time of storage (Choudhary *et al*., 2008). MT treatment reported to check oxidative stress, which mainly caused fruit ascorbic acid content loss during ripening (Galano *et al*., 2011; Gao *et al*.,2016). It was evident from the present study that total phenol content and antioxidant acidity of the stored pineapple were recorded as high in MT treated fruits (Table 6). Highest total phenol and antioxidant activity (% inhibition DPPH) were recorded in the case of the fruits treated with MT @ 8.0mM (T_6) compared with the control (T_7). Treatment of strawberries with melatonin increased DPPH scavenging capacity during storage (Liu *et al*., 2016; Aghdam and Fard, 2017). Researchers found that during storage the clearance of ABTS [2,2’-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)] and DPPH [2,2-Di(4-tert-octylphenyl)-1-picrylhydrazyl] was significantly improved by melatonin treatment, correlated positively with antioxidant capacity and total phenol content (Liu *et al*., 2018; Puerta-Gomez and Cisneros-Zevallos, 2011).

The present investigation showed that pineapple fruits had maximum spoilage and consequently, the lowest shelf life at control compared with MT treated fruits (Fig.3). Pineapple treated with MT @ 8.0mM (T_6) had minimum fruit decay and highest shelf life during ambient storage. Similarly, it was reported that exogenous application of melatonin had reduced fruit decay and extended shelf life in wax apples (Chen *et al*., 2020)) and pear (Zhai *et al*., 2018). The scientists opined that the application of MT upregulates antioxidant enzymes like superoxide dismutase, ascorbate peroxidase and catalase (Gao *et al*., 2016; Aghdam and Fard, 2017; Liu *et al*., 2018) and ascorbate-glutathione cycle (Song *et al*., 2016; Cao *et al*., 2018) that causes a reduction in fruit decay and senescence. Moreover, MT increases the activity of glucose-6-phosphate dehydrogenase, phenylalanine ammonia-lyase and shikimate dehydrogenase which promotes the accumulation of total phenols and thought to prolong the shelf life by inhibiting fungal decay of postharvest fruits (Gao *et al*., 2018).

Conclusion

The present study concluded that different concentrations of melatonin were applied to pineapple cv. Kew fruits dipped in 8.0 mM melatonin (T_6) were the most effective for increasing shelf life, fruit firmness, TSS, total sugar, reducing sugar, ascorbic acid, total carbohydrate, phenol and antioxidant. Also, this treatment reduced postharvest weight loss, fruit decay, decrease in fruit length and diameter. These results suggest that using melatonin @8.0 mM is the most beneficial postharvest treatment for extending shelf life while maintaining the physicochemical qualities of pineapple stored at ambient temperature.

Conflict of interest

The authors declare that they have no conflicts of interest.

REFERENCES

1. Aghdam, M.S. & Fard, J.R. (2017). Melatonin treatment attenuates postharvest decay and maintains nutritional quality of strawberry fruits (*Fragaria anannasa* cv. Selva) by enhancing GABA shunt activity. *Food Chemistry*, 221, 1650-1657. https://doi.org/10.1016/j.foodchem.2016.10.123
2. Anonymous (2018). *Horticulture statistics at a glance* 2018. National Horticulture Board, Horticulture Statictics Division, Ministry of Agriculture & Farmers' Welfare, Government of India.
3. Anonymous (2021). *Agricultural Statistics at a Glance*. Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India. Retrieved from (https://desagri.gov.in/wp-content/uploads/2021/07/Agricultural-Statistics-at-a-Glance-2021-English-version.pdf).
4. AOAC (1990). *Official methods of the analysis*.15th Ed. Association of Analytical Chemists, Washington DC, USA.
5. Ba, L.J., Cao, S., Ji, N., Ma, C., Wang, R. & Luo, D.L. (2022). Effects of melatonin treatment on maintenance of the quality of fresh-cut pitaya fruit. *International Food Research Journal*, 29, 796-805.
6. Badiche-El Hilali, F., Valverde, J.M., García-Pastor, M.E., Serrano, M., Castillo, S. & Valero, D. (2023). Melatonin Postharvest Treatment in Leafy ‘Fino’ Lemon Maintains Quality and Bioactive Compounds. *Foods*, 12, 2979. https://doi.org/10.3390/foods12152979
7. Cao, S., Song, C., Shao, J., Bian, K., Chen, W. & Yang, Z. (2016). Exogenous melatonin treatment increases chilling tolerance and induces defense response in harvested peach fruit during cold storage. *Journal of Agricultural and Food Chemistry*, 64, 5215-5222. https://doi.org/10.1021/acs.jafc.6b01118

8. Cao, S.F., Shao, J.R., Shi, L.Y., Xu, L.W., Shen, Z.M., Chen, W. & Yang, Z. (2018). Melatonin increases chilling tolerance in postharvest peach fruit by alleviating oxidative damage. *Scientific Reports*, 8, 806. https://doi.org/10.1038/s41598-018-19363-5
9. Chen, C.C. & Paull, R.E. (2001). Fruit temperature and crown removal on the occurrence of pineapple fruit translucency. *Scientia Horticulturae*, 88, 85–95. https://doi.org/10.1016/S0304-4238(00)00201-6
10. Chen, Y., Zhang, Y., Nawaz, G., Zhao, C., Li, Y., Dong, T., Zhu, M., Du, X., Zhang, L., Li, Z. & Xu, T. (2020). Exogenous melatonin attenuates postharvest decay by increasing antioxidant activity in wax apple (*Syzygium samarangense*). *Frontiers in Plant Science*, 11, 569779. https://doi.org/10.3389/fpls.2020.569779
11. Choudhary, M.L., Dikshit, S.N., Shukla, N. & Saxena, R.R. (2008). Evaluation of guava (*Psidium guajava* L.) varieties and standardization of recipe for nectar preparation. *Journal of Horticultural Sciences*, 3, 161-163.
12. Dhar, M., Rahman, S.M. & Sayem, S.M. (2008). Maturity and post harvest study of pineapple with quality and shelf life under red soil. *International Journal of Sustainable Crop Production*, 3(2), 69-75.
13. Fan, S., Xiong, T., Lei, Q., Tan, Q., Cai, J., Song, Z., Yang, M., Chen, W., Li, X. & Zhu, X. (2022). Melatonin treatment improves postharvest preservation and resistance of guava fruit (*Psidium guajava* L.). *Foods*, 11(3), 262. https://doi.org/10.3390/foods11030262
14. Galano, A., Tan, D.X. & Reiter, R.J. (2011). Melatonin as a natural ally against oxidative stress: a physicochemical examination. *Journal of Pineal Research*, 51, 1-16. https://doi.org/10.1111/j.1600-079X.2011.00916.x
15. Gao, H., Lu, Z.M., Yang, Y., Wang, D.N., Yang, T., Cao, M.M. & Cao, W. (2018). Melatonin treatment reduces chilling injury in peach fruit through its regulation of membrane fatty acid contents and phenolic metabolism. *Food Chemistry*, 245, 659-666. https://doi.org/10.1016/j.foodchem.2017.10.008
16. Gao, H., Zhang, Z.K., Chai, H.K., Cheng, N., Yang, Y., Wang, D.N., Yang, T. & Cao, W. (2016). Melatonin treatment delays postharvest senescence and regulates reactive oxygen species metabolism in peach fruit. *Postharvest Biology and Technology*, 118, 103-110. https://doi.org/10.1016/j.postharvbio.2016.03.006
17. Gomez, K.A. & Gomez, A.A. (1984). *Statistical Procedure for Agricultural Research*. 2nd Ed. John willey and Sons, New York.
18. Guillen, F., Santamarina, J.M., Garcia-Pastor, M.E., Chen, N.J., Uruu, G. & Paull, R.E. (2022). Postharvest melatonin treatment delays senescence and increases chilling tolerance in pineapple. *LWT Food Science and Technology*, 169, 113989. https://doi.org/10.1016/j.lwt.2022.113989
19. Hong, K., Xu, H., Wang, J., Zhang, L., Hu, H., Jia, Z., Gu, H., He, Q. & Gong, D. (2013). Quality changes and internal browning developments of summer pineapple fruit during storage at different temperatures. *Scientia Horticulturae*, 151, 68–74. https://doi.org/10.1016/j.scienta.2012.12.016
20. Hossain, M. & Bepary, R.H. (2015). Postharvest Handling of Pineapples: A Key Role to Minimize the Postharvest Loss. *International Journal of Recent Scientific Research*, 6, 6069-6075.
21. Hu, M., Li, J. & Rao, J. (2018). Effect of melatonin on ripening and senescence of postharvest kiwifruits. *Food Science*, 39: (2018) 226-232.
22. Hu, W., Yang, H., Tie, W., Yan, Y., Ding, Z., Liu, Y., Wu, C., Wang, J., Reiter, R.J. & Tan, D.X. (2017). Natural variation in banana varieties highlights the role of melatonin in postharvest ripening and quality. *Journal of Agricultural and Food Chemistry*, 65, 9987-9994. https://doi.org/10.1021/acs.jafc.7b03354
23. Joy, P.P. & Rajuva, R.T.A. (2016). *Harvesting and postharvest handling of pineapple*. Pineapple Research Station (Kerala Agricultural University). Retrieved from (http://prsvkm.kau.in).
24. Kamol, S.I., Howlader, J., Sutra Dhar, G.C. & Aklimuzzaman, M. (2014). Effect of different stages of maturity and postharvest treatments on quality and storability of pineapple. *Journal of the Bangladesh Agricultural University*, 12(2), 251-260. DOI: 10.22004/ag.econ.211237
25. Kuang, X., Wang, C., Xiang, M., Deng, L. & Deng, Y.Q. (2008). The impact of deethylene on Yangmei's postharvest physiology and preservation. *Chinese Agricultural Science Bulletin*, 24, 247-251.
26. Li, M., Li, X., Jing, L., Ji, Y., Han, C., Jin, P. & Zheng, Y. (2018). Responses of fresh-cut strawberries to ethanol vapor pretreatment: Improved quality maintenance and associated antioxidant metabolism in gene expression and enzyme activity levels. *Journal of Agricultural and Food Chemistry*, 66, 8382-8390. https://doi.org/10.1021/acs.jafc.8b02647
27. Li, T., Wu, Q., Zhu, H., Zhou, Y., Jiang, Y., Gao, H. & Yun, Z. (2019). Comparative transcriptomic and metabolic analysis reveals the effect of melatonin on delaying anthracnose incidence upon postharvest banana fruit peel. *BMC Plant Biology*, 19, 289. https://doi.org/10.1186/s12870-019-1855-2
28. Liang, C., Zheng, G., Li, W., Wang, Y., Hu, B. & Wang, H. (2015). Melatonin delays leaf senescence and enhances salt stress tolerance in rice. *Journal of Pineal Research*, 59, 91-101. https://doi.org/10.1111/jpi.12243
29. Liu, C., Zheng, H., Sheng, K., Liu, W. & Zheng, L. (2018). Effects of melatonin treatment on the postharvest quality of strawberry fruit. *Postharvest Biology and Technology*, 139, 47-55. https://doi.org/10.1016/j.postharvbio.2018.01.016
30. Liu, J., Yang, J., Zhang, H., Cong, L., Zhai, R., Yang, C., Wang, Z., Ma, F. & Xu, L. (2019). Melatonin inhibits ethylene synthesis via nitric oxide regulation to delay postharvest senescence in pears. *Journal of Agricultural and Food Chemistry*, 67, 2279-2288. https://doi.org/10.1021/acs.jafc.8b06580
31. Liu, S., Huang, H., Huber, D.J., Pan, Y., Shi, X. & Zhang, Z. (2020). Delay of ripening and softening in 'Guifei' mango fruit by postharvest application of melatonin. *Postharvest Biology and Technology*, 163, 111136. https://doi.org/10.1016/j.postharvbio.2020.111136
32. Lufu, R., Ambaw, A. & Opara, U.L. (2019). The contribution of transpiration and respiration processes in the mass loss of pomegranate fruit (cv. Wonderful). *Postharvest Biology & Technology*, 157, 110982. https://doi.org/10.1016/j.postharvbio.2019.110982
33. Mandal, D. & Vanlalawmpuia, C. (2020). Impact of postharvest use of essential oils on quality and shelf life of

Indian pineapple. *Journal of Postharvest Technology*, 8(3), 96-105.
34. Mandal, D., Lalremruata, Hazarika, T.K. & Nautiyal, B.P. (2015). Effect of postharvest treatments on quality and shelf life of pineapple (*Ananas comosus* [L.] Merr. 'Giant Kew') fruits at ambient storage condition. *International Journal of Bio-resource and Stress Management*, 6(4), 490 -496. DOI: 10.5958/0976-4038.2015.00072.X
35. Mukherjee, S. (2019). Recent advancements in the mechanism of nitric oxide signaling associated with hydrogen sulfide and melatonin crosstalk during ethylene-induced fruit ripening in plants. *Nitric Oxide*, 82, 25-34. https://doi.org/10.1016/j.niox.2018.11.003
36. Ningombam, S., Noel, A. & Singh, J. (2019). Postharvest losses of pineapple at various stages of handling from the farm level up to the consumer in Manipur. *International Journal of Agriculture Sciences*, 11, 9235-9237.
37. Onik, J.C., Wai, S.C., Li, A., Lin, Q., Sun, Q., Wang, Z. & Duan, Y. (2021). Melatonin treatment reduces ethylene production and maintains fruit quality in apple during postharvest storage. *Food Chemistry*, 337, 127753. https://doi.org/10.1016/j.foodchem.2020.127753
38. Paull, R.E. (1993). Pineapple and papaya. In: *Biochemistry of fruit ripening* (pp.291-323). Springer, Dordrecht. https://doi.org/10.1007/978-94-011-1584-1_10
39. Pekkarinen, S.S., Stockmann, H., Schwarz, K., Heinonen, I.M. & Hopia, A.I. (1999). Antioxidant activity and partitioning of phenolic acids in bulk and emulsified methyl linoleate. *Journal of Agricultural and Food Chemistry*, 47, 3036–3043. https://doi.org/10.1021/jf9813236
40. Pila, N., Neeta, B.G. & Rao, T.V.R. (2010). Effect of Post harvest treatments on physico chemical characteristics and shelf life of tomato (*Lycopersicon eseulentum* Mill.) fruits during storage. *American-Eurasian Journal of Agriculture and Environmental Sciences*, 9, 470-479.
41. Puerta-Gomez, A.F. & Cisneros-Zevallos, L. (2011). Postharvest studies beyond fresh market eating quality: phytochemical antioxidant changes in peach and plum fruit during ripening and advanced senescence. *Postharvest Biology and Technology*, 60, 220-224. https://doi.org/10.1016/j.postharvbio.2011.01.005
42. Ranganna, S. (1997). *Handbook of Analysis and Quality Control for Fruits and Vegetable Products.* Tata McGraw Hill Publishing Co. Ltd., New Delhi.
43. Rastegar, S., Khankahdani, H.H. & Rahimzadeh, M. (2020). Effect of melatonin treatment on the biochemical changes and antioxidant enzyme activity of mango fruit during storage. *Scientia Horticulturae*, 259, 108835. https://doi.org/10.1016/j.scienta.2019.108835
44. Reiter, R.J., Manchester, L.C. & Tan, D.X. (2005). Melatonin in walnuts: Influence on levels of melatonin and total antioxidant capacity of blood. *Nutrition*, 21(9), 920-924. https://doi.org/10.1016/j.nut.2005.02.005
45. Reiter, R.J., Tan, D.X., Cabrera, J., D'Arpa, D., Sainz, R.M. & Mayo, J.C. (1999). The oxidant/antioxidant network: Role of melatonin. *Biological Signals and Receptors*, 8, 56-63. https://doi.org/10.1159/000014569
46. Remon, S., Venturini, M.E., Lopez-Buesa, P. & Oria, R. (2003). Burlat cherry quality after long range transport: optimisation of packing conditions. *Innovative Food Science and Emerging Technology*, 4, 425-434. https://doi.org/10.1016/S1466-8564(03)00058-4
47. Sadasivam, S. & Manickam, A. (1996). *Biochemical Methods*. New Age International (P) Limited, New Delhi.
48. Sae-Teaw, M., Johns, J., Johns, N.P. & Subongkot, S. (2013). Serum melatonin levels and antioxidant capacities after consumption of pineapple, orange, or banana by healthy male volunteers. *Journal of Pineal Research*, 55 (1), 58-64. https://doi.org/10.1111/jpi.12025
49. Sayka, M.I., Shamsun, N., Jahid, M.M.I., Mahfuza, I., Hoque, M.M., Hoque, R. & Khan, M.A. (2014). Effect of low molecular weight chitosan coating on physico-chemical properties and shelf life extension of pineapple. *Journal of Forest Products and Industries*, 3, 161-166.
50. Sema, A., Maiti, C.S. & Dietholhou. (2011). Pineapple Cultivation in North East India- A Prospective Venture. *Acta Horticulturae*, 902, 69-78. https://doi.org/10.17660/ActaHortic.2011.902.4
51. Sharafi, Y., Jannatizadeh, A., Fard, J.R. & Aghdam, M.S. (2021). Melatonin treatment delays senescence and improves antioxidant potential of sweet cherry fruits during cold storage. *Scientia Horticulturae*, 288, 110304. https://doi.org/10.1016/j.scienta.2021.110304
52. Song, L.L., Wang, J.H., Shafi, M., Liu, Y., Wang, J., Wu, J.S. & Wu, A. (2016). Hypobaric treatment effects on chilling injury, mitochondrial dysfunction, and the ascorbate-glutathione (ASA-GSH) cycle in postharvest peach fruit. *Journal of Agricultural and Food Chemistry*, 64, 4665 -4674. https://doi.org/10.1021/acs.jafc.6b00623
53. Sun, Q., Zhang, N., Wang, J., Zhang, H., Li, D. & Shi, J. (2015). Melatonin promotes ripening and improves quality of tomato fruit during postharvest life. *Journal of Experimental Botany*, 66(3), 657-668. https://doi.org/10.1093/jxb/eru332
54. Tan, D.X., Reiter, R.J., Manchester, L.C., Yan, M.T., El-Sawi, M. & Sainz, R.M. (2002). Chemical and physical properties and potential mechanisms: melatonin as a broad spectrum antioxidant and free radical scavenger. *Current Topics in Medicinal Chemistry*, 2(2), 181-197. DOI: 10.2174/1568026023394443
55. Tijero, V., Muñoz, P. & Munné-Bosch, S. (2019). Melatonin as an inhibitor of sweet cherries ripening in orchard trees. *Plant Physiology and Biochemistry*, 140, 88-95. https://doi.org/10.1016/j.plaphy.2019.05.007
56. Wang, D., Randhawa, M.S., Azam, M., Liu, H., Ejaz, S., Ilahy, R., Qadri, R., Khan, M.I., Umer, M.A., Khan, M.A. & Wang, K. (2022). Exogenous melatonin treatment reduces postharvest senescence and maintains the quality of papaya fruit during cold storage. *Frontiers in Plant Science*, 13. https://doi.org/10.3389/fpls.2022.1039373
57. Wang, J.Z., Zhang, S.L., Zhou, Q., Tao, S.T., Shahrokh, K., & Ye, Y.X. (2012). The effect of six postharvest treatment methods on strawberry fruit quality. *Food Research and Development*, 33, 179-181.
58. Wu, C., Cao, S., Xie, K., Chi, Z., Wang, J. and Wang, H. (2020). Melatonin delays yellowing of broccoli during storage by regulating chlorophyll catabolism and maintaining chloroplast ultrastructure. *Postharvest Biology and Technology*, 172, 111378. https://doi.org/10.1016/j.postharvbio.2020.111378
59. Ze, Y., Gao, H., Li, T., Yang, B. & Jiang, Y. 2021. Insights into the roles of melatonin in maintaining quality and extending shelf life of postharvest fruits. *Trends in Food Science and Technology*, 109, 569–578. https://

doi.org/10.1016/j.tifs.2021.01.051

60. Zhai, R., Liu, J.L., Liu, F.X., Zhao, Y.X., Liu, L.L., Fang, C., Wang, H., Li, X., Wang, Z., Ma, F. & Xu, L. (2018). Melatonin limited ethylene production, softening and reduced physiology disorder in pear (*Pyrus communis* L.) fruit during senescence. *Postharvest Biology and Technology*, 139, 38-46. https://doi.org/10.1016/j.postharvbio.2018.01.017
61. Zhang, Y., Huber, D.J., Hu, M., Jiang, G., Gao, Z., & Xu, X. (2018). Delay of postharvest browning in Litchi fruit by melatonin via the enhancing of antioxidative processes and oxidation repair. *Journal of Agricultural and Food Chemistry*, 66, 7475-7484. https://doi.org/10.1021/acs.jafc.8b01922
62. Zhang, Z., Wang, T., Liu, G., Hu, M., Yun, Z., Duan, X., Cai, K. & Jiang, G. (2021). Inhibition of downy blight and enhancement of resistance in litchi fruit by postharvest application of melatonin. *Food Chemistry*, 347, 129009. https://doi.org/10.1016/j.foodchem.2021.129009