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Effects of Gum Arabic and Warm Water Application on Physicochemical and Qualitative Parameters of Table Grape Fruits at Postharvest

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ABSTRACT

Table grape is a non-climacteric fruit with a short shelf-life. The current study aimed at applying specific treatments to prolong its shelf-life and maintain qualitative characteristics during storage. In a factorial arrange ment and a completely randomized design, the first factor was the storage period and the second factor was the combination of warm water treatments and gum arabic (GA). The fruits were stored at 5 °C and 80% relative humidity in permanent darkness. On days 0, 20, 40, and 60 of the storage period, seven berries from each replicate were randomly sampled and analyzed for physicochemical and qualitative parameters. The storage time negatively affected the qualities of 'Bidane -h Ghermez' table grape fruits. This deterioration in quality was countered by the application of warm water treatments and GA coating, especially by the 45 °C+GA 5% treatment. Compared to the uncoated control group, the application of 45 °C+GA 5% caused a better maintenance of vitamin C (30.43–160.00%), TSS/TA (19.76–21.57%), anthocyanin (37.40–57.75%), antioxidant activity (7.35–36.40%), total phenol (12.01–24.49%), and sensory attributes (66.66–248.50%) in the fruits during storage. Also, this treatment caused lower levels of weight loss (53.27–45.48%), H_2O_2 (9.90–26.55%), and malondialdehyde (8.84–27.92%). Therefore, the application of warm water treatments and GA coating, particularly at 45 °C+GA 5%, had a remarkable role in extending the shelf-life of table grape fruits. In addition to their effective role in storage, warm water and GA are especially recommended because of their low costs.

Introduction

Grapevine (*Vitis vinifera* L.) is a famous fruit species in temperate regions. It is cultivated for several purposes and valuable products. Iran is one of the most important table grape-producing countries in the world and has an annual production of about two million tons (FAOSTAT, 2020). Table grapes are very nutritious due to their high amount of carbohydrates, minerals (P, K, Ca, Mg, Fe, and Mn), vitamins (B6, C, E, and K), and antioxidant compounds (Creasy and Creasy, 2009).

Table grape is a non-climacteric fruit but has a short shelf-life due to weight loss, susceptibility to physical damage, skin and flesh browning, decay, color changes in the berry and rachis, and loss of flavor (ValizadehKaji et al., 2023). Storage at low temperatures and postharvest applications of synthetic chemicals have been used for preserving fruit quality and prolonging the shelf-life of table grape fruits. Nevertheless, storage at low temperatures alone cannot effectively maintain fruit quality during the postharvest period. Since several chemicals have been restricted in many countries, it is necessary to use alternative and safe treatments for maintaining the quality and increasing the shelf life of table grape fruits. In recent years, cost-effective

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methods such as heat treatments and edible coatings have largely been successful in maintaining fruit quality and increasing the postharvest shelf-life (Malekshahi and ValizadehKaji, 2021; Khalil et al., 2022; ValizadehKaji et al., 2023). Edible coatings can decrease water loss and respiratory reactions by creating a semi-permeable layer on the surface of the product. Gum arabic (GA), as a biopolymer, is mostly obtained from the *Acacia senegal* tree. Among edible coatings, GA has a low viscosity and high solubility. Thus, it has been used commercially as a coating on fruits and vegetables (Ali et al., 2010). GA was reportedly used as an edible coating on papaya (Ali et al., 2016), Mexican lime (Atrash et al., 2018), strawberry (Tahir et al., 2018), and guava (Anjum et al., 2020). Pre-storage heat treatment is an emerging technology that is economically cheaper than other techniques. It has been applied commercially to maintain the quality and extend the shelf-life of many fruits and vegetables (Khalil et al., 2022). Heat treatments improve the antioxidant capacity and phenolic compounds of fruits and vegetables (Schöffl et al., 1998). Compared to warm air treatments, warm water treatments are preferred due to more efficient heat transfer in water, ease of use, and short treatment time (Loaiza-Velarde et al., 2003). Nevertheless, heat treatments can negatively affect fruit quality in some respects (Khalil et al., 2022). To minimize the negative effects of heat treatments, a combination of heat treatments and edible coatings was reportedly suggested (Ban et al., 2015; Khalil et al., 2022). Using heat treatments and edible coatings to improve the shelf-life and quality characteristics of various fruits has been reported by several researchers (Nguyen et al., 2020; Vilaplana et al., 2020; Anjum et al., 2020; Khalil et al., 2022). However, the combined effect of heat treatments and edible coatings has rarely been explored, especially on table grape fruits. So far, no research has been conducted on the combined effect of warm water treatments and GA coating on the shelf-life of table grapes during cold storage. Thus, the purpose of the present work was to evaluate the effects of warm water treatments, GA, and their combined use on quality characteristics, shelf-life, physicochemical characteristics, hydrogen peroxide (H_2O_2), and malondialdehyde (MDA) levels in 'Bidaneh Ghermez' table grape fruits during 60 days of storage at 5 °C.

Material and Methods

Plant materials and treatments

Table grape clusters of 'Bidaneh Ghermez' were harvested in mid-September 2021, when the fruits had reached commercial ripening (Brix: 24% ~ 25%). The fruits were harvested from a commercial vineyard in Hezaveh village, Markazi province, Iran. In its climatic zone, rainfall and relative humidity are moderate, while the temperature is relatively high. The vines grew on sandy-clay loam soil under a drip irrigation system, spaced 2 × 2 m, and pruned on 10th March to 8 canes with 12 buds. Immediately, fruit clusters were transferred to the postharvest laboratory at Arak University. The selected table grape clusters were uniform in size, shape, and color. They were randomly divided into six groups of 60 for the following treatments in three replicates. Each replicate contained 20 individual clusters. The first, second, and third sets were immersed in water at different temperatures [22 (control), 45 and 50 °C] for 2 min. The fourth, fifth, and sixth sets were immersed in water at different temperatures (22, 45, and 50 °C) for 2 min and then dipped in 5% GA solution for 5 min (22 °C+GA 5%, 45 °C+GA 5% and 50 °C+GA 5%). These treatments were selected based on preliminary experiments in the laboratory. After being air-dried, all clusters were packaged in polyethylene terephthalate and stored at 5 °C and 80% relative humidity (ValizadehKaji et al., 2023). The storage chamber was permanently dark for 60 days. On days 0, 20, 40, and 60, seven berries from each replicate were randomly sampled and measured.

Weight loss

The weight loss percentage was measured using [(A–B)/A] x 100 equation, where A was the fruit weight, following the treatment (initial weight), and B was the fruit weight at 20-day intervals (days 20, 40, and 60) during storage (ValizadehKaji et al., 2023).

Vitamin C

According to Ranganna (1977), the vitamin C of the fruits was determined by oxidizing ascorbic acid with 2,6-dichlorophenol endophenoldye. The results were expressed as mg 100 g^{-1} fresh weight (FW).

TSS (total soluble solids) and TA (titratable acidity)

To assess the TSS concentration of berry juice, a digital refractometer (Atago, PAL-1, Japan) was used and the results were expressed as °Brix %.

TA was determined by titration with 0.1 N NaOH up to a pH of 8.1, using 1 mL of diluted juice in 25 mL distilled water, and the results were expressed as tartaric acid %. TSS to TA ratio was calculated by dividing TSS to TA.

Anthocyanin content

According to Kim et al. (2003), the anthocyanin content was determined by the pH differential method. Absorbance was measured using a spectrophotometer (Cary Win UV 100; Varian, Sydney, Australia) at 520 and 700 nm. Readings were expressed as cyanidin-3-glycoside equivalents per 100 g of fruit fresh weight (FW).

Antioxidant activity

According to Brand-Williams et al. (1995), the antioxidant activity of the fruit extract was determined based on the radical scavenging activity in reacting with DPPH (2,2-diphenyl-1-picrylhydrazyl). In brief, 100 µL of the methanol extract was mixed sufficiently with a 1900 µL DPPH solution (Sigma Aldrich, USA). After 30 min, the absorbance was measured at 517 nm against a blank (methanol). The percentage of antioxidant activity as inhibition percentage of free radical DPPH was estimated using the following formula:

$$Antioxidant\ activity\ percentage = [(\frac{blank\ absorbance - extract\ absorbance}{blank\ absorbance}] \times 100$$

Total phenol content

Total phenol content was determined using a Folin–Ciocalteu reagent based on Singleton et al. (1999) with some modifications. Approximately, 0.5 g of fruit pulp and peel was homogenized in methanol (85%) and centrifuged at 6000 × g for 10 min. Then, 1 mL of the Folin–Ciocalteu reagent (10%) and 0.3 mL of each diluted methanolic extract (10%) were mixed and vortexed. One mL of 7% sodium carbonate solution was added to the mixture after 5 min. After shaking the final solution for 90 min at ambient temperature, the absorbance was measured at 765 nm using a spectrophotometer (Cary Win UV 100, Varian, Australia). Total phenolic contents were estimated by applying a calibration curve drawn for the gallic acid standard solution as mg gallic acid g^{-1} FW.

H_2O_2

The H_2O_2 concentration of table grape fruits was determined according to ValizadehKaji et al. (2023). Approximately, 0.5 g of fruit pulp and peel was ground and homogenized in 10 mL of 0.1% (w/v) trichloroacetic acid (TCA). The mixture was centrifuged at 6,000 × g for 15 min, where 0.5 mL of the supernatant, 0.5 mL of 10 mM potassium phosphate buffer, pH 7.0, and 0.1 mL of reagent were mixed (0.1 M KI in double-distilled freshwater). The supernatant absorbance was measured at 390 nm using a spectrophotometer (Cary Win UV 100, Varian, Australia) against a blank (0.1% TCA). The H_2O_2 concentration was estimated by applying a standard curve of established H_2O_2 concentrations as µmol g^{-1} FW.

MDA

Lipid peroxidation of the membrane was determined according to Heath and Packer (1968). Briefly, 100 mg of each fruit pulp and peel sample was homogenized in 5 mL of 0.1% (w/v) trichloroacetic acid (TCA) and centrifuged at 6,000 rpm for 5 min. The supernatant was collected and lipid peroxidation was estimated via the MDA concentration as µmol g^{-1} FW.

Sensory characteristics

Five panelists were asked to evaluate the sensory characteristics of the stored table grape berries. Their appearance, flavor, color, berry abscission, decay, shattering, cracking, and overall acceptability were assessed on a ranked scale of 1-5, where 1 = very bad, 2 = bad, 3 = medium, 4 = suitable, and 5 = excellent. The average values were included to assess the acceptability of the consumers.

Shelf life of fruits

The shelf-life of table grape fruits was calculated by recording the days that the fruits remained in good condition during storage without spoilage. The end of shelf-life was when the spoilage of fruits exceeded 50% (ValizadehKaji et al., 2023).

Statistical analysis

The current study was carried out as a factorial based on a completely randomized design (CRD) with two factors. The first factor was the storage period (0, 20, 40, and 60 days) and the second was the combination of warm water treatments and GA [22 °C+GA 0% (control), 45 °C+GA 0%, 50 °C+GA 0%, 22 °C+GA 5%, 45 °C+GA 5% and 50 °C+GA 5%]. Data were analyzed using a GLM procedure SAS software (ver. 9.1). Significant differences were assessed using Duncan's multiple range test ($P \leq 0.05$). Each treatment group had three replications.

Results

There interactions between storage period and treatments significantly affected weight loss, antioxidant activity, total phenol content, H_2O_2, MDA, and sensory attributes of fruits. However, the interactions between storage period and treatments had no significant effect on vitamin C, TSS, TA, TSS/TA, pH, and anthocyanin content of the table grape fruits (Table 1).

Table 1. Variance analysis of physicochemical and qualitative properties of 'Bidaneh Ghermez' table grape in response to GA (gum arabic) and warm water treatments during cold storage.

S.O.V	df	Mean Square											
		Weight loss	Vitamin C	TSS	TA	TSS/TA	pH	Anthocyanin	Antioxidant activity	Total phenol	H_2O_2 concentration	MDA concentration	Sensory scores
Period	3	104.74 **	5.18 **	11.57 **	0.03 **	4600.15 **	1.98 **	5.03 **	1708292.65 **	194772.48 **	1.64**	1.91**	21.19 **
Treatments	5	5.75 **	0.87**	3.96 ns	0.04 ns	703.62 *	0.24 ns	3.19 **	1070.69 **	2145.78 **	0.07**	0.12**	6.68 **
Period× Treatments	18	0.73 **	0.15 ns	0.77 ns	0.04 ns	110.10 ns	0.04 ns	0.39 ns	319.23 *	284.84 **	0.01**	0.02**	1.02 **
Error	48	0.18	0.12	2.54	0.01	238.20	0.10	0.23	143.76	14.32	0.001	0.001	0.13
CV (%)	-	12.78	12.17	6.13	13.12	18.17	8.74	9.40	1.96	0.98	2.76	2.25	16.66

ns, * and **: not significant, significant at P≤0.05 and P≤0.01, respectively. TSS: total soluble solids, TA: titratable acidity, H_2O_2: hydrogen peroxide, MDA: malondialdehyde

Storage period

All measured traits were significantly affected by the storage period (Table 1). A significant decrease was found in vitamin C (25.14–48.00%), TA (10.81–29.72%), antioxidant activity (14.83–79.64%), total phenol (18.82–48.56%), and sensory scores (16.60–51.00%) of the table grape berries during storage. On the other hand, a significant increase was observed in weight loss (3.27–5.30%), TSS (2.87–7.54%), TSS/TA (16.72–56.89%), pH (4.70–21.76%), H_2O_2 (19.31–85.22%), and MDA (18.64–71.18%) of the table grape berries during storage. The anthocyanin content of the table grape berries increased slightly (9.09–18.86%) until day 40 and then decreased (Table 2).

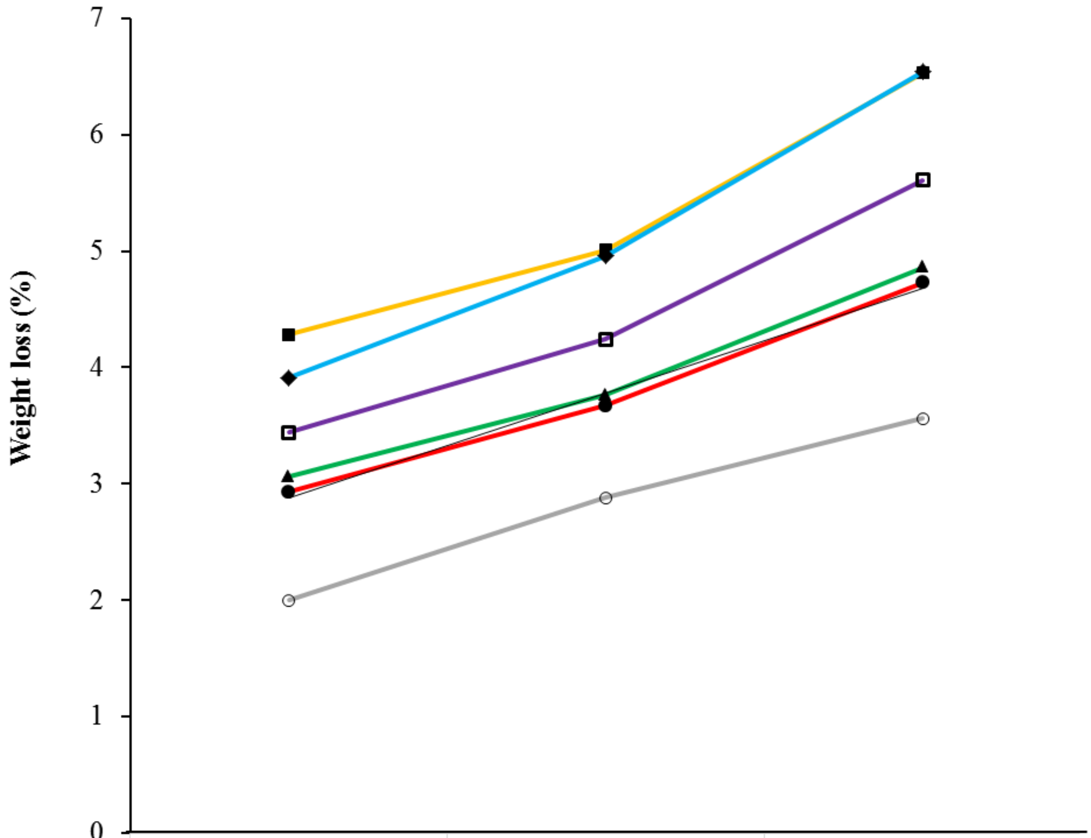
Table 2. Effect of storage period on physicochemical and qualitative properties of treated and untreated table grape berries during cold storage.

Storage days	Weight loss (%)	Vitamin C (mg 100 g^{-1})	TSS (°Brix)	TA (%)	TSS/TA	pH	Anthocyanin content (mg 100 g^{-1})	Antioxidant activity (%)	Total phenol (mg kg FW^{-1})	H_2O_2 concentration (µmol g^{-1} FW)	MDA concentration (µmol g^{-1} FW)	Sensory scores
0	0.00 ^{d}	3.50 ^{a}	25.05 ^{c}	0.37 ^{a}	67.21 ^{d}	3.40 ^{c}	4.40 ^{c}	902.98 ^{a}	510.58 ^{a}	0.88 ^{d}	1.18 ^{d}	5.00 ^{a}
20	3.27 ^{c}	2.62 ^{b}	25.77 ^{bc}	0.33 ^{b}	78.45 ^{c}	3.56 ^{c}	4.80 ^{b}	769.04 ^{b}	414.47 ^{b}	1.05 ^{c}	1.40 ^{c}	4.17 ^{b}
40	4.08 ^{b}	2.33 ^{c}	26.27 ^{ab}	0.30 ^{c}	89.23 ^{b}	3.88 ^{b}	5.23 ^{a}	484.50 ^{c}	320.18 ^{c}	1.34 ^{b}	1.74 ^{b}	3.45 ^{c}
60	5.30 ^{a}	1.82 ^{d}	26.94 ^{a}	0.26 ^{d}	105.45 ^{a}	4.14 ^{a}	4.67 ^{b}	183.80 ^{d}	262.62 ^{d}	1.63 ^{a}	2.02 ^{a}	2.45 ^{d}

Mean values followed by similar letters within a column are not significantly different from each other at $P \leq 0.05$ (Duncan's multiple range test). Data are mean values of three replicates. TSS: total soluble solids, TA: titratable acidity, H_2O_2: hydrogen peroxide, MDA: malondialdehyde.

Weight loss

Weight loss in table grape berries intensified substantially (3.27–5.30%) during storage (Table 2). However, fruits that received warm water treatments, GA, and their combination showed a smaller degree of weight loss, compared to the control fruits. The effect of 45 °C+GA 5% treatment was significantly higher than that of the other treatments. In comparison with the untreated fruits, the weight loss of berries under the 45 °C+GA 5% treatment was 53.27%, 42.51%, and 45.48% lower after 20, 40, and 60 days of storage, respectively (Fig. 1).

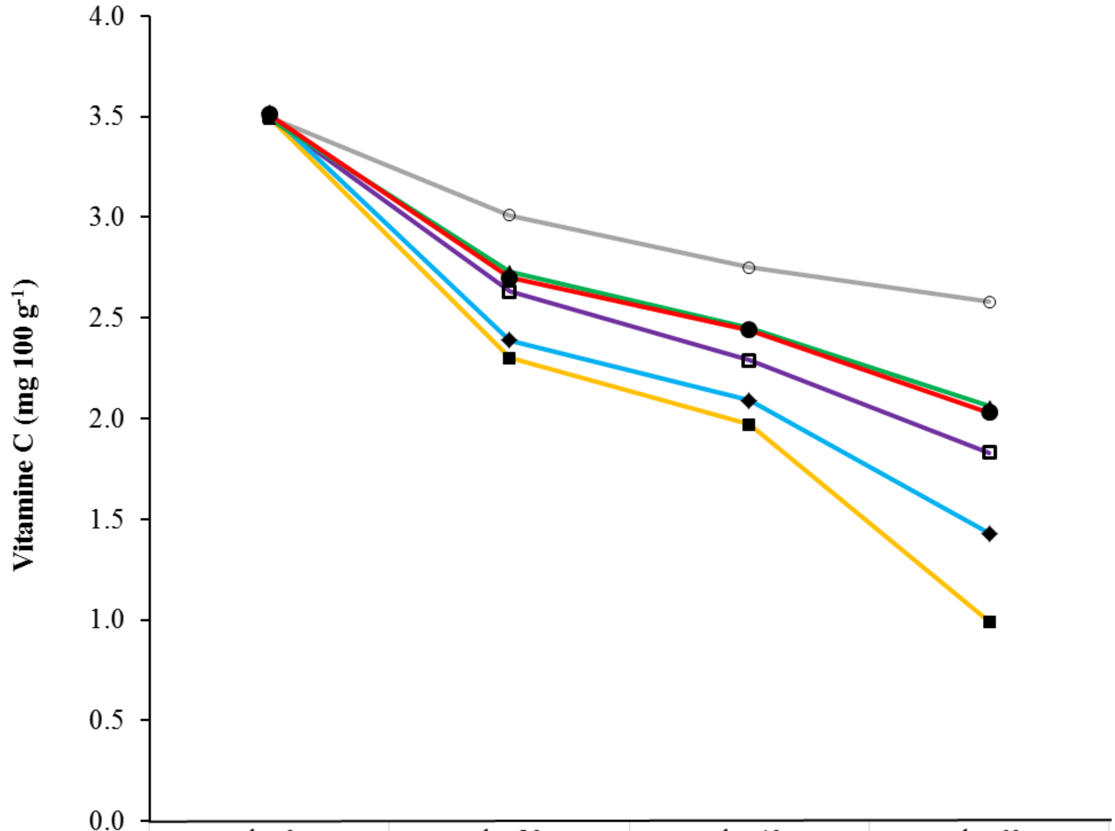


	day 20	day 40	day 60
22 °C+GA 0%	4.28±0.90 cd	5.01±0.64 bc	6.53±0.96 a
45 °C+GA 0%	3.44±0.44 efg	4.24±0.46 cde	5.61±0.29 b
50 °C+GA 0%	3.91±0.42 de	4.96±0.68 bc	6.54±0.22 a
22 °C+GA 5%	3.06±0.59 fg	3.76±0.17 def	4.86±0.14 bc
45 °C+GA 5%	2.00±0.23 h	2.88±0.21 g	3.56±0.30 def
50 °C+GA 5%	2.93±0.20 g	3.67±0.49 def	4.73±0.59 c

Fig. 1. The interaction effect of treatment and time on the weight loss of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other at P≤0.05 (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum arabic.

Vitamin C

The results showed that the vitamin C decreased significantly (25.14–48.00%) in the berries during storage (Table 2). However, the decline in vitamin C was less pronounced in fruits that received warm water treatments, GA, and their combination. The highest vitamin C content was recorded in fruits treated with 45 °C+GA 5% which showed a significant difference from the control and the treatment group of 50 °C+GA 0% (Fig. 2). On days 20, 40, and 60, berries treated with 45 °C+GA 5% had 30.43%, 40.00%, and 160.00% higher vitamin C content than the untreated berries, respectively (Fig. 2).



	day 0	day 20	day 40	day 60
22 °C+GA 0%	3.5±0.00 a	2.3±0.51 b	2.0±0.10 b	1.0±0.53 c
45 °C+GA 0%	3.5±0.00 a	2.6±0.55 ab	2.3±0.35 ab	1.8±0.25 ab
50 °C+GA 0%	3.5±0.04 a	2.4±0.50 b	2.1±0.45 b	1.4±0.28 bc
22 °C+GA 5%	3.5±0.05 a	2.7±0.15 ab	2.5±0.27 ab	2.1±0.20 ab
45 °C+GA 5%	3.5±0.00 a	3.0±0.10 a	2.8±0.56 a	2.6±0.85 a
50 °C+GA 5%	3.5±0.01 a	2.7±0.13 ab	2.4±0.31 ab	2.0±0.23 ab

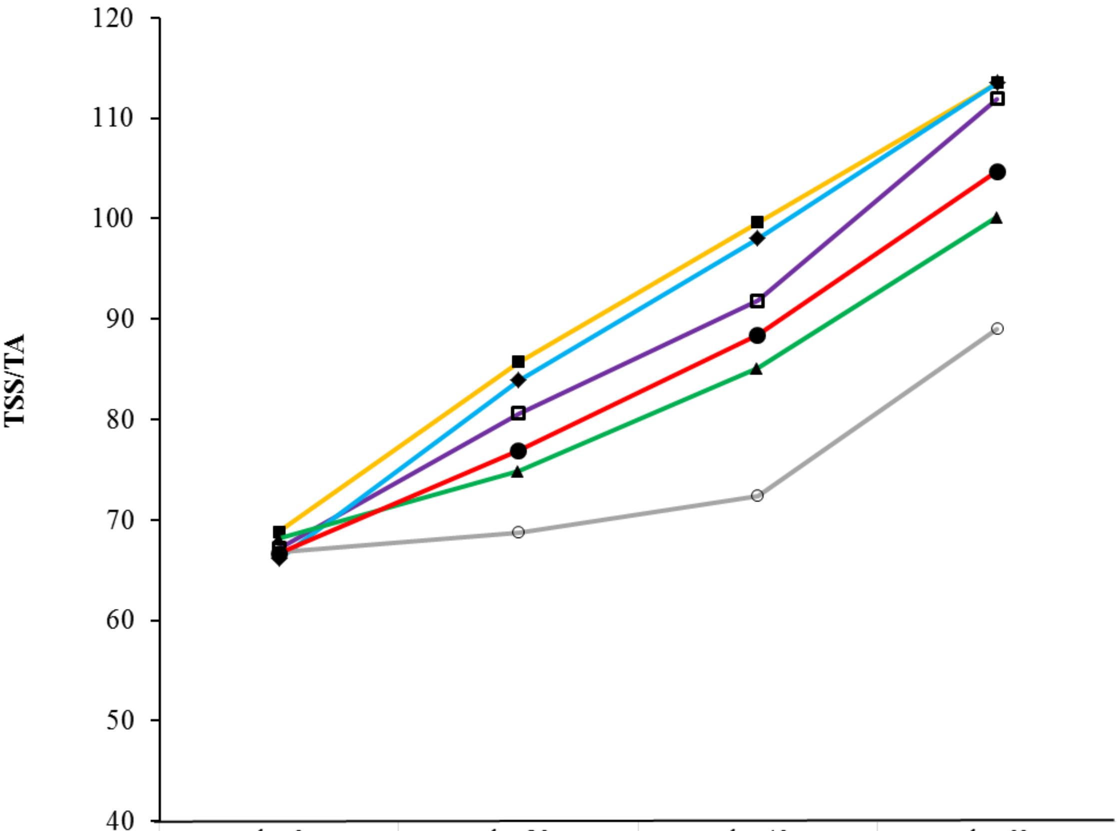
Fig. 2. Effect of the combination of warm water treatments and GA (gum arabic) on the vitamin C of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other at P≤0.05 (Duncan's multiple range test). Significant differences were separately assessed on 0, 20, 40, and 60 days. Data are mean values of three replicates ± standard deviation.

TSS, TA, and pH

During the storage period, significant increases were observed in the TSS (2.87–7.54%) and pH (4.70–21.76%) while the TA decreased (10.81–29.72%) (Table 2). However, warm water treatments, GA, and their combination had no significant effect on TSS, TA, and pH of the table grape berries (Table 1).

TSS/TA

The results showed that the TSS/TA of table grape berries increased (16.72–56.89%) during the storage period (Table 2). However, the TSS/TA of fruits that received warm water treatments, GA, and their combination was lower than that of the untreated fruits. At all sampling times, fruits of the control treatment had the greatest TSS/TA, whereas fruits treated with 45 °C+GA 5% showed the lowest values (Fig. 3). Nevertheless, significant differences were only observed between the control and 45 °C+GA 5% treatment (Fig. 3). Compared to the control treatment, the TSS/TA of fruits treated with 45 °C+GA 5% was 19.76%, 27.30%, and 21.57% lower after 20, 40, and 60 days of cold storage, respectively (Fig. 3).

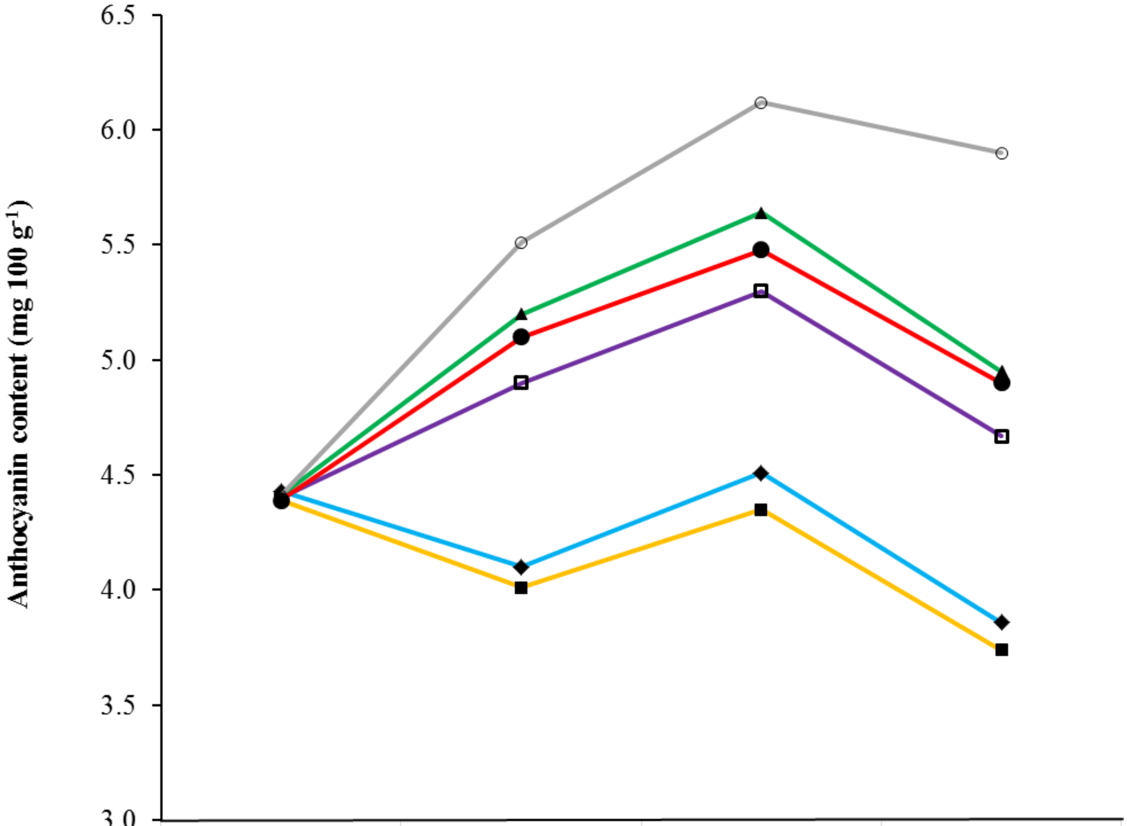


	day 0	day 20	day 40	day 60
22 °C+GA 0%	68.80±6.30 a	85.71±7.66 a	99.61±7.75 a	113.49±9.58 a
45 °C+GA 0%	67.17±7.03 a	80.58±9.22 ab	91.82±9.72 ab	111.91±5.98 a
50 °C+GA 0%	66.11±7.81 a	83.91±9.10 a	98.03±9.93 a	113.51±9.51 a
22 °C+GA 5%	68.11±7.58 a	74.83±4.32 ab	85.12±9.45 ab	100.12±9.61 ab
45 °C+GA 5%	66.77±3.18 a	68.77±4.05 b	72.41±5.74 c	89.00±9.08 b
50 °C+GA 5%	66.62±6.39 a	76.92±4.75 ab	88.41±5.77 ab	104.67±8.23 ab

Fig. 3. Influence of the combination of warm water treatments and GA (gum arabic) on the TSS/TA (total soluble solids/titratable acidity) of table grape fruits during the storage period. Mean values followed by similar letters are not significantly different from each other (P≤0.05) (Duncan's multiple range test). Significant differences were separately assessed on days 0, 20, 40, and 60. Data are mean values of three replicates ± standard deviation.

Anthocyanin content

Anthocyanin content increased (9.09–18.86%) in the table grape berries in response to most treatments until day 40 and then gradually decreased (Table 2 and Fig. 4). Meanwhile, treated fruits had higher anthocyanin content than untreated fruits. At all sampling times, the highest anthocyanin content was obtained in response to 45 °C+GA 5% treatment, although no significant difference was found between this treatment and most other treatments on days 20 and 40 (Fig. 4). On days 20, 40, and 60, berries treated with 45 °C+GA 5% had 37.40%, 40.68%, and 57.75% higher anthocyanin content than the untreated berries, respectively (Fig. 4).

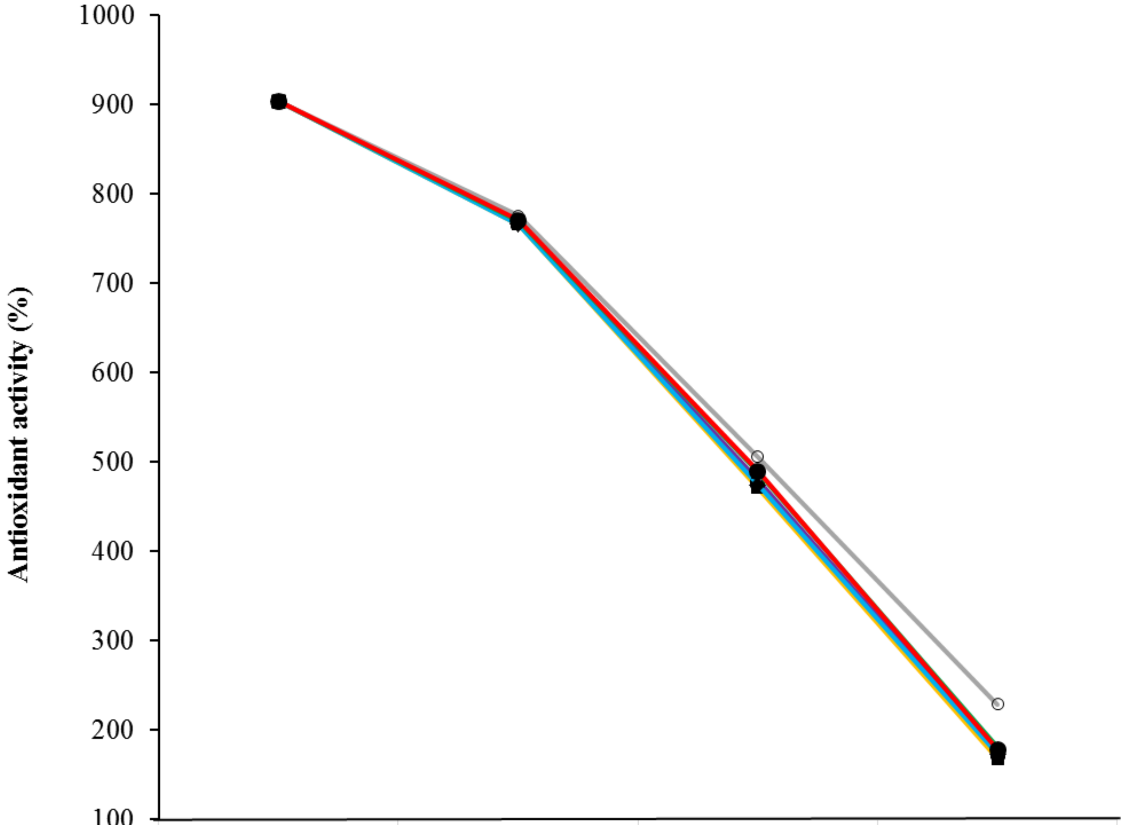


	day 0	day 20	day 40	day 60
22 °C+GA 0%	4.39±0.19 a	4.01±0.05 b	4.35±0.52 b	3.74±0.62 d
45 °C+GA 0%	4.40±0.05 a	4.90±0.59 a	5.30±0.55 ab	4.67±0.81 bc
50 °C+GA 0%	4.43±0.16 a	4.10±0.25 b	4.51±0.85 b	3.86±0.27 cd
22 °C+GA 5%	4.41±0.17 a	5.20±0.40 a	5.64±0.36 a	4.95±0.50 b
45 °C+GA 5%	4.41±0.15 a	5.51±0.04 a	6.12±0.08 a	5.90±0.29 a
50 °C+GA 5%	4.39±1.23 a	5.10±0.45 a	5.48±0.41 a	4.90±0.05 b

Fig. 4. Effect of warm water treatments and GA (gum arabic) on the anthocyanin content of table grape fruits during the storage period. Mean values followed by similar letters are not significantly different from each other ($P \leq 0.05$) (Duncan's multiple range test). Significant differences were separately assessed on days 0, 20, 40, and 60. Data are mean values of three replicates ± standard deviation.

Antioxidant activity

The antioxidant activity of table grape berries declined considerably (14.83–79.64%) during storage (Table 2). On day 20, treated and untreated berries did not show significant differences in their level of antioxidant activity. Beyond day 20, however, only berries in the 45 °C+GA 5% treatment had significantly greater antioxidant activity than the untreated ones (Fig. 5). Compared to the uncoated berries, the antioxidant activity of berries under the 45 °C+GA 5% treatment was 7.35% and 36.40% higher after 40 and 60 days of cold storage, respectively (Fig. 5).

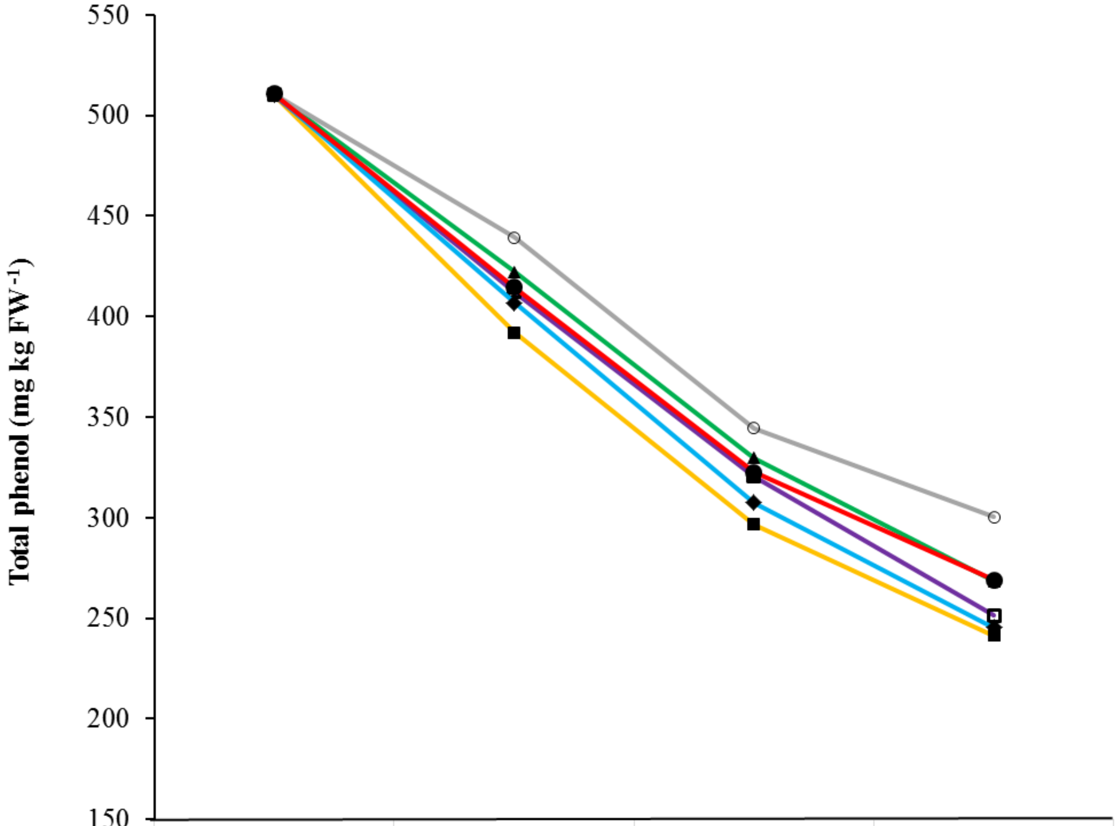


	day 0	day 20	day 40	day 60
22 °C+GA 0%	903.33±5.77 a	765.66±1.15 b	471.06±9.33 d	167.66±2.51 f
45 °C+GA 0%	903.56±3.83 a	768.26±2.19 b	478.93±7.65 d	175.03±8.13 f
50 °C+GA 0%	903.66±4.61 a	765.80±1.05 b	474.13±5.47 d	172.93±5.25 f
22 °C+GA 5%	903.13±2.73 a	769.16±3.81 b	487.83±9.46cd	180.60±3.41 f
45 °C+GA 5%	903.13±0.23 a	775.03±5.05 b	505.70±8.97 c	228.70±1.58 e
50 °C+GA 5%	903.20±0.17 a	770.33±4.04 b	489.33±9.25cd	177.86±9.41 f

Fig. 5. The interaction effect of treatment and time on the antioxidant activity of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other (P≤0.05) (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum arabic.

Total phenol content

During the storage time, the total phenol content of table grape berries decreased significantly (18.82–48.56%) (Table 2). However, fruits that received warm water treatments, GA, and their combination showed more total phenol content compared to untreated fruits of the control. The highest total phenol content resulted from the 45 °C+GA 5% treatment which was significantly greater than the other treatments (Fig. 6). On days 20, 40, and 60, berries treated with 45 °C+GA 5% had 12.01, 16.04, and 24.49% higher total phenol content than the untreated berries, respectively (Fig. 6).

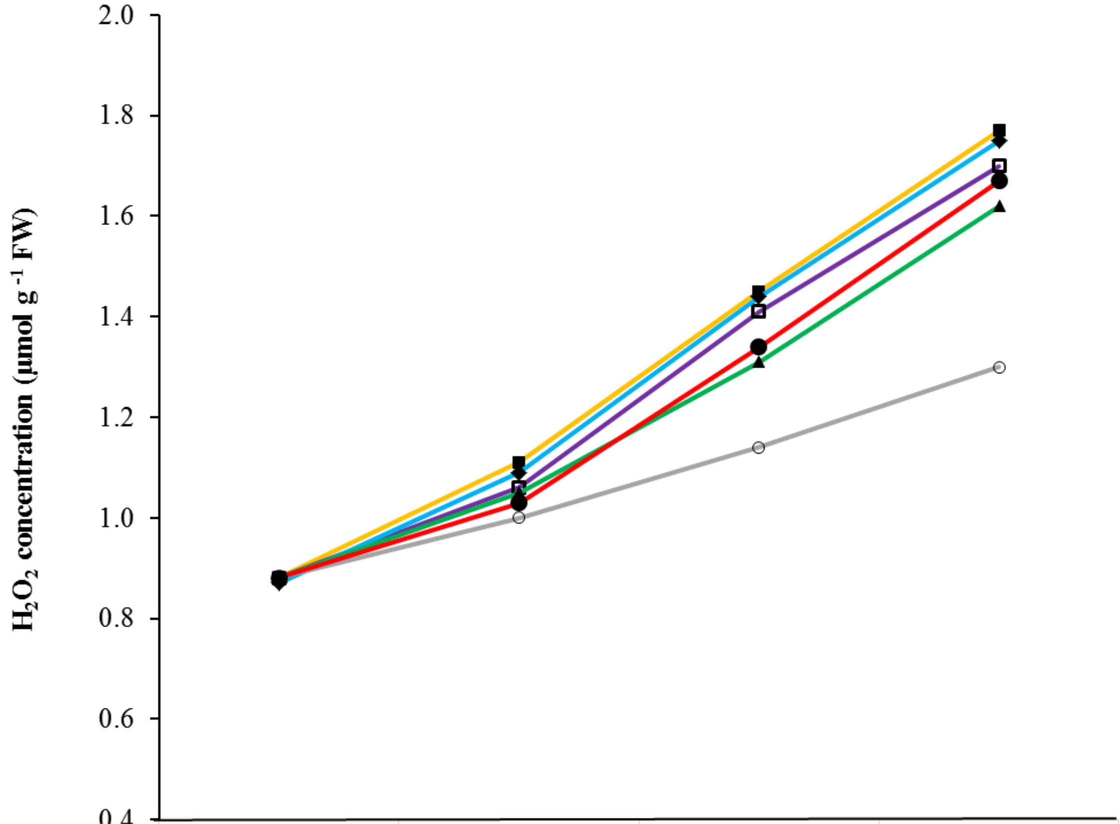


	day 0	day 20	day 40	day 60
22 °C+GA 0%	510.20±4.75 a	392.03±6.55 f	296.70±2.69 k	241.23±2.73 n
45 °C+GA 0%	510.16±0.51 a	412.33±3.78 de	320.63±2.28 i	251.36±2.82 m
50 °C+GA 0%	510.33±1.52 a	406.66±9.07 e	307.43±2.13 j	245.40±5.71 mn
22 °C+GA 5%	510.63±0.11 a	422.06±5.74 c	329.50±3.93 h	268.30±0.85 l
45 °C+GA 5%	510.73±1.55 a	439.13±0.80 b	344.30±5.47 g	300.33±4.04 k
50 °C+GA 5%	510.63±1.52 a	414.63±3.38 d	322.53±1.00 i	269.10±0.51 l

Fig. 6. The interaction effect of treatment and time on the total phenol content of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other (P≤0.05) (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum arabic.

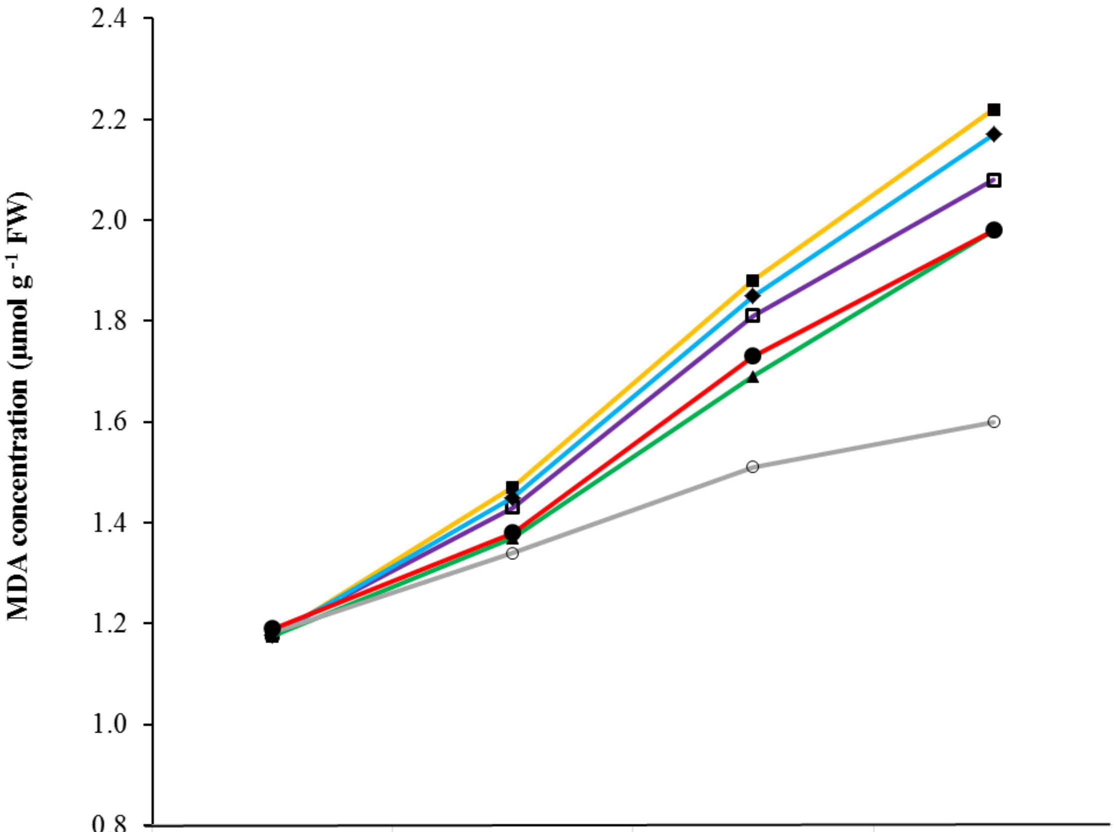
H_2O_2 and MDA concentration

H_2O_2 and MDA concentrations of table grape berries increased significantly during the storage period (Table 2). However, treated fruits had lower H_2O_2 and MDA concentrations than the untreated fruits (Fig. 7 and Fig. 8). The lowest H_2O_2 and MDA concentrations occurred in response to the 45 °C+GA 5% treatment, although no significant difference was found between this treatment group and other treatment groups on day 20 (Fig. 7 and Fig. 8). After 20, 40, and 60 days of storage at 5 °C, berries treated with 45 °C+GA 5% had 9.90, 21.37, and 26.55% lower H_2O_2 concentrations than the untreated berries, respectively (Fig. 7). In addition, the MDA concentrations of berries under the 45 °C+GA 5% treatment were 8.84%, 19.68%, and 27.92% lower than the uncoated berries after 20, 40 and 60 days of cold storage, respectively (Fig. 8).



	day 0	day 20	day 40	day 60
22 °C+GA 0%	0.88±0.01 l	1.11±0.06 gh	1.45±0.02 e	1.77±0.01 a
45 °C+GA 0%	0.88±0.00 l	1.06±0.01 hij	1.41±0.03 e	1.70±0.03 bc
50 °C+GA 0%	0.87±0.00 l	1.09±0.03 ghi	1.44±0.02 e	1.75±0.02 ab
22 °C+GA 5%	0.88±0.00 l	1.05±0.02 jk	1.31±0.03 f	1.62±0.01 d
45 °C+GA 5%	0.88±0.00 l	1.00±0.03 kl	1.14±0.02 g	1.30±0.01 f
50 °C+GA 5%	0.88±0.01 l	1.03±0.02 ijk	1.34±0.01 f	1.67±0.10 cd

Fig. 7. The interaction effect of treatment and time on the H_2O_2 (hydrogen peroxide) concentration of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other (P≤0.05) (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum arabic.

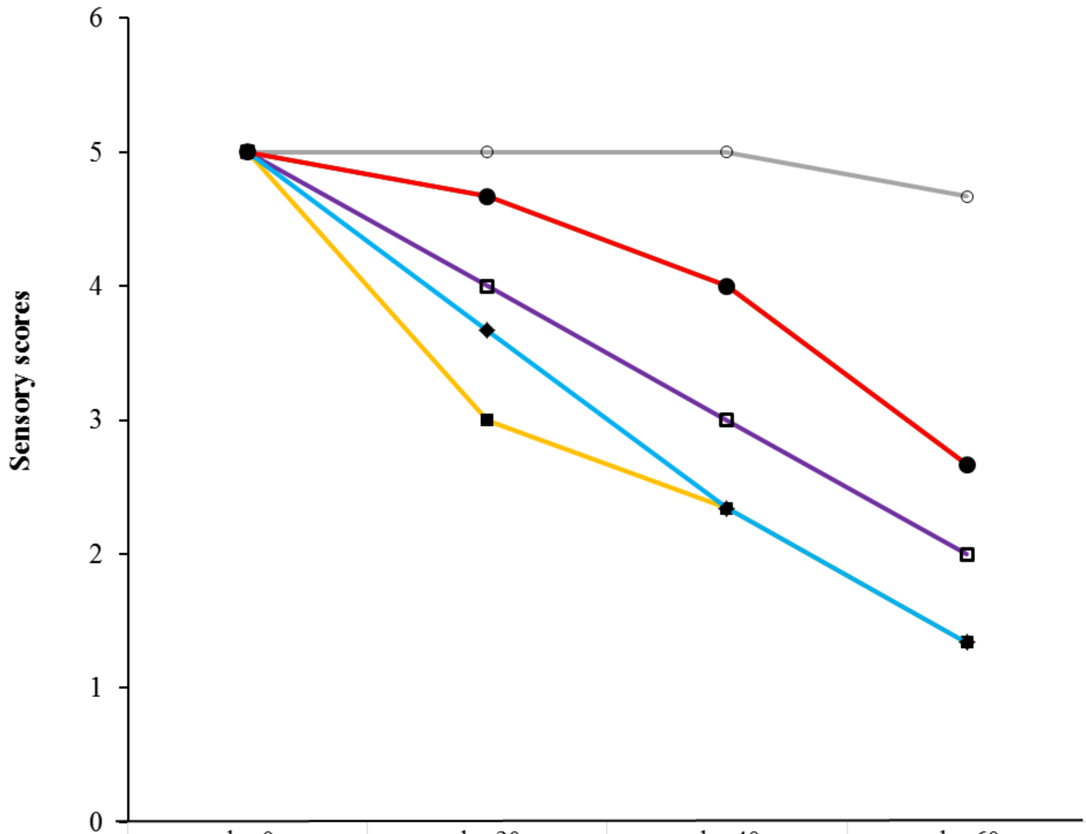


	day 0	day 20	day 40	day 60
22 °C+GA 0%	1.17±0.05 l	1.47±0.02 hi	1.88±0.01 d	2.22±0.03 a
45 °C+GA 0%	1.18±0.04 l	1.43±0.00 ij	1.81±0.01 e	2.08±0.02 b
50 °C+GA 0%	1.18±0.04 l	1.45±0.02 hi	1.85±0.01 de	2.17±0.02 a
22 °C+GA 5%	1.18±0.04 l	1.37±0.01 jk	1.69±0.03 f	1.98±0.01 c
45 °C+GA 5%	1.18±0.03 l	1.34±0.04 kl	1.51±0.03 h	1.60±0.00 g
50 °C+GA 5%	1.19±0.02 l	1.38±0.02 jk	1.73±0.02 f	1.98±0.08 c

Fig. 8. The interaction effect of treatment and time on the MDA (malondialdehyde) concentration of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other ($P \leq 0.05$) (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum arabic.

Sensory characteristics

The results of the current study showed that the sensory characteristics of berries decreased significantly during storage (16.60–51.00%) (Table 2). However, the sensory characteristics of treated fruits were far better than untreated fruits, where the effect of 45 °C+GA 5% was significantly higher than the other treatments, with the exception of 22 °C+GA 5% and 50 °C+GA 5% treatments on day 20 (Fig. 9). Compared to the control fruits, the sensory characteristics of berries treated with 45 °C+GA 5% were 66.66%, 113.67%, and 248.50% higher after 20, 40, and 60 days of cold storage, respectively (Fig. 9).



	day 0	day 20	day 40	day 60
22 °C+GA 0%	5.00±0.00 a	3.00±0.57 d	2.34±0.57 de	1.34±0.57 f
45 °C+GA 0%	5.00±0.00 a	4.00±0.57 bc	3.00±0.00 d	2.00±0.00 e
50 °C+GA 0%	5.00±0.00 a	3.67±0.00 c	2.34±0.57 d	1.34±0.57 f
22 °C+GA 5%	5.00±0.00 a	4.67±0.57 ab	4.00±0.00 bc	2.67±0.57 de
45 °C+GA 5%	5.00±0.00 a	5.00±0.57 a	5.00±0.00 a	4.67±0.57 ab
50 °C+GA 5%	5.00±0.00 a	4.67±0.00 ab	4.00±0.00 bc	2.67±0.57 de

Fig. 9. The interaction effect of treatment and time on the sensory attributes of table grape fruits during storage. Mean values followed by similar letters are not significantly different from each other ($P \leq 0.05$) (Duncan's multiple range test). Data are mean values of three replicates ± standard deviation. GA: gum Arabic

Shelf-life

The application of warm water treatments, GA, and their combination significantly increased the shelf-life of table grape berries (Fig. 10). The longest shelf-life (55.66 days) was obtained from the 45 °C+GA 5% treatment, which was significantly different from the other treatments. The shortest shelf-life (33.66 days) was obtained in the control group, although no significant difference was observed between the control and the 50 °C+GA 0% treatment (Fig. 10).

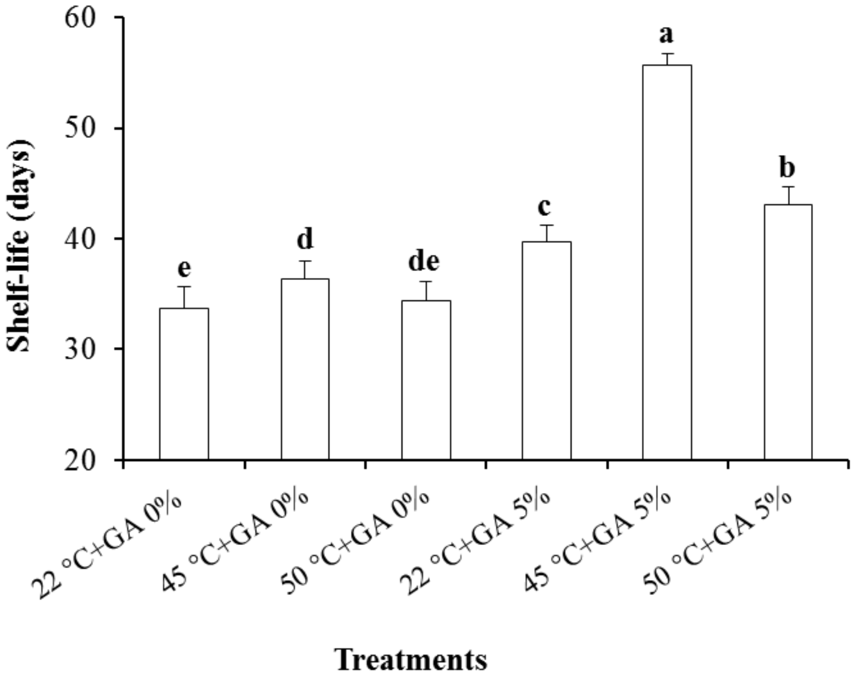


Fig. 10. Effect of warm water treatments and GA (gum arabic) on the shelf-life of table grape fruits stored at 5 °C. Mean values followed by similar letters are not significantly different from each other (P≤0.05) (Duncan's multiple range test). Vertical bars indicate standard deviation.

Discussion

Due to consumer concerns about synthetic chemicals, alternative and safe methods such as heat treatments and edible coatings are regularly studied for their effectiveness in maintaining fruit quality (Khalil et al., 2022; ValizadehKaji et al., 2023). The current study revealed that warm water treatments, GA, and their combination, especially 45 °C+GA 5%, can be used for maintaining the quality of harvested table grapes. Warm water treatments, GA and their combination considerably reduced weight loss in table grapes during 60 days of storage (5 °C) (Fig. 1). Using heat treatments to decrease weight loss in fruits is consistent with Khalil et al. (2022) on mango, Hosseinifarahi et al. (2020) on apricot, and Hosseini et al. (2015) on pear. Heat treatment tends to melt the epicuticular fruit waxes while covering and sealing cracks and lenticels on the fruit surface, which leads to a decrease in the water loss of fruits (Fallik and Lurie, 2007). In addition, our findings are consistent with those obtained by Anjum et al. (2020) on guava, Atrash et al. (2018) on Mexican lime, Ali et al. (2016) on papaya, and Ali et al. (2010) on tomato, reporting that the application of GA coating decreased the weight loss of fruits. The decrease in the weight loss of fruits, as a consequence of GA application, most likely results from the effects of GA as a semi-permeable barrier against O_2, CO_2, and moisture, which can thus decrease respiration and water loss (Ali et al., 2010; Ali et al., 2016). In this study, the vitamin C of berries was reduced during storage (Table 2), which is consistent with previous reports (Nourozi and Sayyari, 2020; Khalil et al., 2022). The decline in vitamin C content was less pronounced in treated fruits than in untreated ones (Fig. 2). Similarly, findings on the positive effects of warm water treatments on vitamin C during storage have been obtained in dragon fruit (Nguyen et al., 2020) and mango (Khalil et al., 2022).

Our findings are consistent with those reported by Daisy et al. (2020), which suggested that GA coating preserves vitamin C in mango fruits during storage. During cold storage, the TSS, TSS/TA, and pH increased, whereas the TA decreased (Table 2). The results were consistent with previous findings by Hosseinifarahi et al. (2020) on apricot and Khalil et al. (2022) on mango. Changes in the said parameters probably result from water loss during the storage, consumption of organic acids in the respiratory process, and the hydrolysis of polysaccharides into soluble sugars (ValizadehKaji et al., 2023).

Nonetheless, significant differences did not occur between the treated and untreated fruits regarding their TSS, TA, and pH (Table 1), which is contrary to the results of previous studies (Atrash et al., 2018; Daisy et al., 2020;

Hosseinifarahi et al., 2020; Khalil et al., 2022). In addition, the TSS/TA of treated fruits was lower than in untreated fruits (Fig. 3). A decrease in the TSS/TA of fruits by GA coating was indicated in Mexican lime (Atrash et al., 2018) and guava (Anjum et al., 2020), similar to our findings. Also, the results of the current study are consistent with previous ones by Vilaplana et al. (2020), who reported that papaya fruits treated with a combination of warm water treatments and edible coatings had a lower TSS/TA than untreated fruits. In contrast, Hong et al. (2007) reported that the TSS/TA of mandarins under heat treatments increased during storage, contrary to the results of the present work (Fig. 3).

According to this study, the anthocyanin content initially increased and decreased after 40 days (Table 2 and Fig. 4). These findings support those reported by Saki et al. (2019) on figs and ValizadehKaji et al. (2023) on table grapes, where the anthocyanin content of fruits increased during the early days of storage, probably due to an increase in sugar accumulation, thereby enhancing the synthesis of anthocyanins (Varasteh et al., 2012). However, treated fruits had higher anthocyanin content than untreated fruits (Fig. 4), thereby confirming previous results by Mirdehghan et al. (2007) that the anthocyanin content of pomegranate fruits treated with warm water treatments was higher than control fruits during storage. Similar findings on the positive effects of edible coatings and their role in the anthocyanin content of fruits during storage have been obtained from apricot (Nourozi and Sayyari, 2020) and table grapes (ValizadehKaji et al., 2023).

Since edible coatings cause changes in the internal atmosphere of coated fruits, they reduce the activity of polyphenol oxidase and peroxidase enzymes, which slows down the degradation of anthocyanins (Varasteh et al., 2012). However, the results of the current study are contrary to Tahir et al. (2018), having indicated that strawberry fruits treated with GA had lower anthocyanin content than untreated fruits. In this study, a continuous decrease in the antioxidant activity of the table grape berries occurred during the storage period (Table 2). Nonetheless, the said decrease in the treated fruits was smaller than in the uncoated fruits (Fig. 5). Similarly, declines reportedly occurred in the antioxidant activity of table grapes during the storage period (Ehtesham Nia et al., 2021; ValizadehKaji et al., 2023).

In contrast, Nguyen et al. (2020) stated that the antioxidant activity of dragon fruits increased during storage, contrary to our findings. The antioxidant activity of fruits is a manifestation of bioactive compounds such as ascorbic acid and phenolic components (Anjum et al., 2020). Degradation of these compounds leads to a reduction of antioxidant activity (Maqbool et al., 2011). Likewise, in this study, a continuous decrease in vitamin C and total phenol during the storage period (Fig. 2 and Fig. 6) showed similar trends to that of the antioxidant activity of fruits (Fig. 5). Furthermore, similar findings exist regarding the positive effects of heat treatments on antioxidant activity of Satsuma mandarin (Shen et al., 2013), Mexican lime (Atrash et al., 2018), and dragon fruit (Nguyen et al., 2020) during storage, probably because of the role of heat treatments in stimulating protective enzymes against oxidative damages to the fruits (Vicente et al., 2006).

In addition, our findings are consistent with those reported by Atrash et al. (2018) on Mexican lime, Tahir et al. (2018) on strawberry, and Khaliq et al. (2015) on mango, having indicated that the antioxidant activity of fruits treated with GA was significantly higher than non-coated controls during storage. However, the results of this work are contrary to Anjum et al. (2020) in that edible coatings of GA and *Aloe vera* gel did not influence the antioxidant activity of guava fruits, and a higher antioxidant activity occurred in uncoated fruits. This contrast in behavior may have emanated from differences in guava fruits and cultivars compared to other fruits.

Our findings indicated that the total phenol content of table grape berries decreased during cold storage (Table 2), contrary to some reports in the literature (Nourozi and Sayyari, 2020; Nguyen et al., 2020; Hu et al., 2022), which showed an increase in total phenolic content of fruits during the storage period. However, treated fruits had higher levels of phenol content compared to the control (Fig. 6). These findings are similar to previous results by Nguyen et al. (2020) and Ban et al. (2015), who reported the positive effects of heat treatments, edible coatings, and their combination on the total phenolic content of fruits during the storage period. Furthermore, Atrash et al. (2018) and Tahir et al. (2018) indicated that the phenolic contents of fruits coated with GA were higher than uncoated fruits during storage, parallel to the results of this work. Since phenolic compounds are directly involved in plant defense reactions, it is valuable to maintain high levels of phenolic compounds in fruits during the storage period.

In this work, a steady increase in H_2O_2 and MDA concentrations occurred during the storage period (Table 2), similar to some reports in the literature (Ghorbani et al., 2017; ValizadehKaji et al., 2023). However, this increase in treated fruits was smaller than in non-treated fruits (Fig. 7 and Fig. 8). Similar findings exist on the positive effects of warm water treatments and edible coatings on the H_2O_2 and MDA of fruits (Kahramanoğlu et al., 2020; Nguyen et al., 2020). Furthermore, the results of this study are consistent with reports that showed a combination of heat treatment and edible coatings resulted in lower levels of H_2O_2 and MDA in fruits (Nguyen et al., 2020; Jiang et al., 2022). The low concentrations of H_2O_2 and MDA in the treated table grape berries probably result from a high antioxidant activity (ValizadehKaji et al., 2023), as documented in this work (Fig. 5).

In the present research, a continuous decrease in the sensory characteristics of berries occurred during the storage period (Table 2); nevertheless, warm water treatments, GA, and their combination, particularly at 45 °C+GA 5%, considerably maintained the sensory characteristics of berries during storage (Fig. 9). Similarly, combining warm water treatments and edible coatings had a better effect on the sensory attributes than the warm-water treatments or edible coating used separately (Ban et al., 2015; Vilaplana et al., 2020).

The obtained results revealed that the application of warm water treatments, GA, and their combination significantly increased the shelf-life of table grape berries (Fig. 10). Increases in the shelf-life of fruits with the application of heat treatments, edible coatings, and their combination were reportedly described in the case of Mexican lime (Atrash et al., 2018), mango (Khalil et al., 2022) and *Akebia trifoliata* (Jiang et al., 2022), which is consistent with the results of this work.

Conclusion

The application of warm water treatment, GA coating, and their combination, precisely at 45 °C+GA 5%, had significant effects on most of the measured parameters, particularly since it helped to decrease weight loss, H_2O_2, and MDA while maintaining higher levels of vitamin C, anthocyanin, antioxidant activity, and total phenol in table grape berries. Therefore, warm water and GA, especially at 45 °C+GA 5%, assisted in the shelf-life extension of 'Bidaneh Ghermez' fruits. The main advantages of GA are its edibility, nontoxic nature, and cost-effectiveness compared to other synthetic coatings. In addition, it offers a glazy attractive appearance to the fruits (Kabbashi et al., 2018). The quick warm-water dip is a cost-effective method to maintain fruit quality and functional value (Shen et al., 2013).

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Author contributions

Babak ValizadehKaji and Ahmadreza Abbasifar conceived and designed the research. Saied Maleki conducted the experiments. Babak ValizadehKaji analyzed the data. Babak ValizadehKaji and Ahmadreza Abbasifar wrote the manuscript. All authors read and approved the manuscript.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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