Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2021) 45: 79-90
© TÜBİTAK
doi:10.3906/tar-2004-104

Potential effects of storage period, warehouse locations, and methyl jasmonate in long-term stored garlic bulbs

Selen AKAN, Nurdan TUNA GUNES*
Department of Horticulture, Faculty of Agriculture, Ankara University, Ankara, Turkey

Received: 27.04.2020 • **Accepted/Published Online:** 29.09.2020 • **Final Version:** 10.02.2021

Abstract: In this study, the effect of methyl jasmonate (MeJA) treatments (10^{-3} and 10^{-5} M) and two different storage locations such as Ankara and Taşköprü, on some quality parameters, such as weight loss, L* values, soluble solids content, firmness, titratable acidity, total phenolic content, antioxidant capacity, vitamin C and allicin content in garlic bulbs (*Allium sativum* cv. 'Taşköprü') were investigated during a storage period of six months with three replications (30 bulbs or 120 g cloves). Based on storage periods, storage locations and MeJA treatment effects, the results showed that the storage period significantly affected all parameters except allicin content. MeJA treatments positively affected weight loss, L* values, soluble solids content, total phenolics, and antioxidant capacity. At the end of the storage, the lowest weight loss was determined in 10^{-3} M MeJA as 7.8%, the highest L* value was 85.40 (10^{-5} M) and soluble solids content was maintained in 10^{-5} M MeJA (40.26%). Higher total phenolics and antioxidant capacity were found in 10^{-3} M MeJA (24.44 mg $100g^{-1}$) and 10^{-5} M MeJA (66.88% I), respectively. Moreover, warehouse location significantly affected L* values, titratable acidity, total phenolics While Ankara location caused the highest L* (86.07), total phenolics (26.12 mg $100g^{-1}$), and delayed increase in titratable acidity (0.89% citric acid) in samples, the highest values in allicin content (31.42 mg kg^{-1}) was determined in samples stored in the Taşköprü location. Overall, MeJA treatment could be considered as promising treatment for long-term storage of bulbs in commercial warehouses.

Key words: Allicin, *Allium sativum* L., antioxidant capacity, methyl jasmonate, postharvest, quality

1. Introduction

Garlic (*Allium sativum* L.) is one of the most popular vegetable species around the world. It has been widely used for nutrition and medicinal purposes since ancient times. Turkey provides 0.5% of total world garlic production contributing with 143 thousand tons of garlic. Out of this production, 0.32% is exported, 8% is used for vegetative production, and unfortunately 20%-30% is wasted during storage, marketing or handling and the rest is used for processing or freshly domestic consumption (TurkStat, 2019). Garlic is a crucial product for industry because of its wide functional uses and this species can be considered as an industrial product. Long-term storage of an industrial product is extremely important in terms of ensuring raw materials for processing industry, restaurants, and markets as well. In this concept, Turkey has over 200 companies processing garlic. These industrial companies demand raw materials with high quality from producers or suppliers throughout the year.

Soluble solids, moisture and reducing sugar content, color, pH value and firmness of garlic bulbs are important quality criteria in terms of consumer preferences (Pardo et al., 2007). Additionally, several enzymes, amino acids, phenolic contents, antioxidant capacity, and many sulfur compounds, such as alliin, allicin, ajoene, diallyl sulfide, diallyl disulfide, diallyl trisulfide vinyldithiines, S-allyl cysteine, S-allylmercaptocystein, and others in garlic are considered as important markers because these compounds are related to many therapeutic effects of this species such as antithrombotic, antiaging, cardiovascular protection, and cancer prevention (Huang et al., 2015).

The bulb quality of garlic is dramatically deteriorated due to unsuitable ambient conditions during long storage period (Volk and Rotindo, 2004). During the storage period, sprouting, rooting, weight loss, discoloration, off-flavor and high microbial activity observed in garlic bulbs are taken into consideration as quality losses. Aforesaid disorders may be a result of some pre and postharvest factors, such as excessive nitrogen fertilization, more and/or less irrigation, early harvest, insufficient curing of bulbs, or overload stacking of storage rooms (Petropoulos et al., 2017).

* Correspondence: tuna@agri.ankara.edu.tr

Garlic bulbs and cloves are stored commercially in either warehouses or ordinary cold stores. Since the ambient temperature is higher and relative humidity (RH) is lower in warehouses than regular cold stores, total product loss during long-term storage period can reach 25%–40% (Tripathi and Lawande, 2006). Storage life of garlic is 3–5 months and total storage losses are 30%–45% under ambient conditions (Sharma et al., 2020). According to the report by the National Horticultural Research and Development Foundation of India[1], the storage losses in garlic bulbs were 12.5% at 1–5 °C temperature with 75% RH compared to 42.4% losses at ambient temperature. Storage of garlic bulbs at room temperature (20–30 °C) for 1–2 months resulted in loss of firmness and discoloration due to weight loss (Cantwell, 2000). Purwanto et al. (2019) stated that weight losses of garlic bulbs were higher (4.4%–5.7%) when stored at room temperature (29–31 °C).

In Turkey, this species has been widely stored in noncooled warehouses in the production area. Postharvest losses in garlic are ca. 20%–25%. Hence, some storage conditions such as overload stacking in warehouse room, deficient ventilation, and high storage temperature result in increasing postharvest losses and to limit storage period.

Phytohormones are known to play an important role in checking postharvest losses like weight loss, rotting, sprouting etc. during long-term storage period (Ram et al., 2019). One of them is methyl jasmonate (MeJA), which is a derivative of jasmonic acid (JA), formed from an enzymatic methylation pathway. It actively functions in processes related to oxidative stress, mediating the activity of antioxidant enzymes. It has been regarded as a vital cell regulator in plants and is accepted as an ecofriendly agent (Asrey and Barman, 2015). In recent years, many researches focused on the efficacy of exogenous MeJA applications on maintaining quality during storage and shelf-life periods in various freshly harvested horticultural crops (Khan et al., 2018; Akan et al., 2019; Ozturk et al., 2019).

Taşköprü county supplies a large part of Turkey's garlic production. Harvested garlic is either stored directly in local warehouses in this county or transported to the bigger consumption provinces, such as Ankara and İstanbul. There are no available data about postharvest losses during long-term storage of garlic in warehouses at production (Taşköprü) and marketing (Ankara) locations. So, the aims of this research are firstly to determine postharvest losses in quality and quantity in warehouses at different locations, and secondly to observe efficacy of MeJA on maintaining some quality parameters in garlic bulbs during long-term storage in warehouses.

[1] http://nhrdf.org/en-us/pPostHarvestTech_G

2. Materials and methods

2.1. Materials

In this research, 'Taşköprü' garlic (*Allium sativum* sub var. *sativum*) cultivar was used as a plant material due to having high titratable acidity, soluble solids content, and antioxidant capacity (Akan, 2019). The bulbs were hand-harvested from Taşköprü district (41°30'50" N, 34°12'53" E, 553 m elevation), north of Turkey at the beginning of August in 2012. The bulbs were harvested at commercially mature stage according to bulbing ratios of 0.2%–0.3% and between 38% and 50% of leaves in senescence (Ledesma et al., 1997; Del Pozo and González, 2005). Harvested bulbs were fully cured under environmental conditions (35–38 °C and 45%–55% RH) in the production area for 10–12 days. After that, experimentally suitable bulbs with high quality were selected based on free from damages, uniformity and size (45–55 mm in diameter).

2.2. Methyl jasmonate (MeJA) treatments and storage conditions

Garlic bulbs (except controls) were treated with MeJA (Sigma Aldrich, 392707) solutions (10^{-3} and 10^{-5} M) at 20 °C by dipping with a duration of 3 min. MeJA concentrations were selected based on the results of previous studies (Wang, 1988; Cantwell et al., 2003a). After MeJA treatments, all treated-samples were air-dried and all samples including controls were stored in two different locations (SLs) in dark conditions for six months. Half of the samples were stored in containers in a commercial warehouse in Taşköprü, production location. During the storage period, the warehouse was cooled via outside cold air by opening doors.

The other half of the samples (nontreated) were transported by a covered truck at ambient conditions within 3 h to Ankara University Faculty of Agriculture Department of Horticulture, treated with MeJA (10^{-3} and 10^{-5} M), and then stored in the experimental warehouse for six months. In this warehouse, the cooling of the room was enabled by ventilation during the whole nighttime throughout the storage period. In both warehouses, values of temperature and RH during the storage period were recorded using a thermo-hygrometer (Wewell, VHM 140) (Figure).

2.3. Quality assessments

Weight loss (WL) in garlic bulbs was determined by weighing the same bulbs at each analysis times with a digital scale (Mettler Toledo, Ohio, USA) and presented as percentage (%). Color of cloves were measured by a chroma meter (Minolta CR-200) in CIE L*, a*, b* color space system, and changes in color were expressed using L* values.

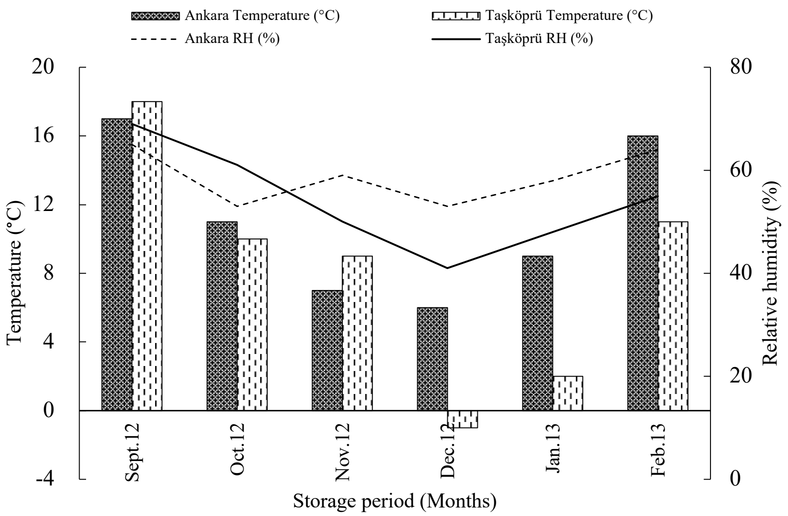

Figure. Monthly average temperatures at different storage locations.

Soluble solids content (SSC) was analyzed with digital Abbe refractometer (Leica Microsystems GmbH, Wetzlar, Germany) in squeezed garlic juice. A texture analyzer (Stable Microsystems, TA-XT Plus) was used to measure firmness of garlic cloves according to Akan et al. (2019). Titratable acidity (TA) was measured in garlic juice by a titrator (DL 50 Mettler Toledo, Ohio, USA) and results were presented as citric acid %. The Folin–Ciocalteu colorimetric method as described in Lu et al. (2011) was used for total phenolic content (TPC) determinations using a spectrophotometer (Shimadzu UV/VIS). The results were presented as mg gallic acid per 100 g fresh weight (mg GAE 100g^{-1} fresh weight).

Antioxidant capacity (AOC) as 2,2-diphenyl-1-picrylhydrazyl (Sigma, D9132) (DPPH) radical scavenging activity was measured based on the procedure described by Brand-Williams et al. (1995). AOC was calculated as percentage of inhibition (I%), Vitamin C content was determined as in Casado et al. (2004) with some modifications. Briefly, a 5 g sample was homogenized with 20 mL of metaphosphoric acid (Merck) solution (6%) by a homogenizer (IKA-Labortechnik, Ultra-turrax T25) at 24,000 rpm for 20 s. After centrifuging, 14,000 rpm at 1 °C for 15 min, the supernatant was filtered with a membrane filter (0.45 µm), collected in amber color vials, and then analyzed with a high-pressure liquid chromatography (HPLC) (Shimadzu LC 10 ATVP) equipped with C_{18} column (Phenomenex Luna, 250 × 4.6 mm, 5 µm) and diode array detector (DAD). The results were calculated based on external *L*-ascorbic acid standards at different concentrations and data were expressed as mg kg^{-1}. Allicin content were determined by the method of Arzanlou and Bohlooli (2010) with partial modifications. For extraction, 10 g of garlic puree was sonicated with 20 mL double distilled water (DDW) in an ultrasonicator (VWR, ultrasonic cleaner) for 5 min. Then it was held in the dark for 1 min for enzymatic reactions. After vortexing for 10 s and centrifuging (Sigma 3K30) at 12,600 rpm for 20 min at 4 °C, the extract was analyzed by a HPLC (Shimadzu-LC-10 ATVP). C_{18} column (Phenomenex Luna, 250 × 4.6 mm, 5 µm), DAD detector and CH_3CN (Sigma-Aldrich Chemie GmbH, Hamburg, Germany)/DDW (37.5/63.5, v/v) at a flow rate of 0.6 mL/min^{-1} at 30 °C were used for separation of allicin. Chromatograms were defined at 220 nm and quantifications were realized based on external allicin standard. External allicin standard was obtained from Prof. Dr. Mohsen Arzanlou (Ardabil University of Medical Sciences, Iran).

2.4. Experimental design and statistical analysis

This research was based on completely randomized design (CRD) with three replications. Each replication included ten bulbs and analysis was carried out on ten randomly selected cloves. All samples from different warehouses were simultaneously analyzed. Data were subjected to analysis of variance (ANOVA) in MINITAB Software (Trial Version, United Kingdom) at $P \leq 0.05$ and significant differences among means were computed by Duncan's multiple-range test in MSTAT-C software. Storage periods (SP), storage locations (SLs), and MeJA treatments were considered as independent variables and interactions among these variables were searched at $P \leq 0.05$ error level. ArcSin transformations were applied to percentage data before statistical evaluations.

3. Results and discussion

At harvest time, L* (lightness), soluble solids content (SSC), firmness, titratable acidity (TA), total phenolic content (TPC), antioxidant capacity (AOC), vitamin C content, and allicin content of samples were determined as 87.88%, 39.25%, 11.1 N, 0.5% citric acid, 29.2 mg GAE 100 g^{-1}, 76.31% I, 56.95 mg kg^{-1}, and 87.16 mg kg^{-1}, respectively.

During the storage period, average storage temperatures recorded in warehouses in Ankara and Taşköprü were 11 and 8.2 °C, respectively (Figure). Clear differences in temperature were observed during 4 and 5 months of storage, and the warehouse in Taşköprü had lower mean temperatures than that of the Ankara location. Also, average RH values of locations were recorded as 65% and 62% in Ankara and Taşköprü, respectively (Figure).

WL was interactively affected by storage period (SP) × storage locations (SLs) × MeJA treatments (MeJA) (P ≤0.05) as seen in Table 1. SLs effect individually was not found significant on WL whereas longer SPss caused higher WL in garlic bulbs in both warehouses. The lowest WLs were determined in control (7.30%), 10^{-5} M MeJA (7.42%), and 10^{-3} M MeJA (7.53%) treatments at Taşköprü location, which were 7.75%, 8.20%, and 8.46% in control, 10^{-3} M MeJA, and 10^{-5} M MeJA-treated garlics, respectively, at the Ankara location at the end of the storage period. It was thought that high temperature and RH at the Ankara location enhanced the WL of garlic bulbs. Madhu et al. (2019) stated that WL is greatly influenced by the storage temperature. Nei et al. (2007) found that WL of stored garlic bulbs was 3.5%–4% at 25 °C, Sukkaew and Tira-Umphon (2012) found 4%–11% WL at room temperature for 120 days storage, and Purwanto et al. (2019) determined 18.76% WL at room temperature at the end of the storage period. We can thus conclude that WL depends on the increase in metabolic activity of garlic bulbs. Martins et al. (2016) stated that storage quality of garlic bulbs is closely related to the breaking of bulb dormancy, which is adjusted by variety, storage temperature, and storage duration. According to our results, the effect of MeJA on this parameter mostly depends on warehouses at different locations and storage periods. MeJA inhibited the increase of WL in peeled garlic cloves, 'Arrayana' mandarins, and strawberry fruits (Gómez et al., 2017; Akan et al., 2019; El-Mogy et al., 2019).

L* (lightness) is also a crucial sensory attribute of garlic bulbs, all of the dependent variables interactively affected L* values (P ≤ 0.05) (Table 1). A significant reduction of L* values was recorded in 10^{-3} M MeJA (from 84.54 to 80.72) at Taşköprü location (Table 1). This parameter showed fluctuations during the storage period and a clear decrease was detected in the 4th month of storage in all groups (Table 1). Decrease in L* values during the storage period was also supported by Kang and Hong (2001), who stored garlic bulbs at 0 °C for 4 months in controlled atmospheric conditions. Apart from this, some L* values increased minimally in some groups (SP × Ankara × 10^{-3} M MeJA and SP × Taşköprü × 10^{-5} M MeJA). The causes of decrease in L* values could be as follows: (i) occurring of yellowish color, (ii) enzymatic and/or nonenzymatic browning (Kang and Lee, 1999; Dronachari et al., 2010; Veríssimo et al., 2010), (iii) mechanical damages during harvest and handling (Cantwell et al., 2003b).

SP (P = 0.000) and MeJA (P = 0.000) treatments individually affected SSC in garlic bulbs. Generally, average SSC values increased during whole storage period in all samples. SSC was only related to SP × MeJA interactions (P ≤ 0.05) (Table 2). Similarly, Kang and Hong (2001) pointed out that SSC of garlic bulbs increased to 46% after four months. While an increase in SSC could be a result of an increase in weight loss (Akan et al., 2019), the reason for a decrease in SSC could be the breakdown of sugars in cloves (Torun, 2015). In the current study, the highest SSC (41.23%) was recorded in samples treated with 10^{-5} M MeJA in the 5th month (Table 2). In previous reports, postharvest MeJA treated fruits, such as raspberry and Japanese plum, exhibited higher SSC values (Khan et al., 2018).

Firmness values in all treatments changed based on SP (P ≤ 0.05) (Table 2). The highest decrease (30%) in firmness was observed in the 6th month (8.00 N) of storage period. Kang and Hong (2001), Vázquez-Barrios et al. (2006), Bayat et al. (2010), and Sharma et al. (2020) also reported data that support the current finding. Meanwhile, a decrease in firmness could be associated with an increase in WL during the storage period or some other biochemical reactions. Hence, Torun (2015) noticed that firmness loss in garlic depended on pectin and pectic acid breakdown.

The titratable acidity (TA) content of garlic bulbs changed based on SP, SLs, and SLs × MeJA interactions (P ≤ 0.05) (Table 2). TA content significantly increased from 0.67% in the first month to 1.17% at the end of the storage period. Pardo et al. (2007), Dronachari et al. (2010), and Akan et al. (2019) observed similar increasing trends in TA during storage of garlic bulbs or cloves. Although there is no attractive finding expressing the reason of increasing trend in TA in fresh fruit and vegetables, Soccol et al. (2006) expressed increase in TA in foods by higher microbial activity, especially increase in *Penicillium* spp. in stored foods. In the current research, with the aim of maintaining TA values close to harvest time, 10^{-3} M MeJA for Ankara, and 10^{-5} M MeJA for Taşköprü location were successful treatments for preventing increase of TA (Table 2). This discrepancy could be due to the different storage conditions in two locations (Figure).

Apart from SP, SLs and MeJA treatments, SP × SLs, SP × MeJA, and SLs × MeJA interactions significantly affected total phenolic content of cloves (P ≤ 0.05) (Table 2). TPC values changed between 23 and 28 mg GAE $100g^{-1}$ and showed gradual decline during the storage period. Fei et al. (2015) observed an increase in TPC of garlic cloves upto the 6^{th} week and then a decrease, while regular increases in

Table 1. Effects of MeJA treatments on the WL and L* values of garlic bulbs stored for 6 months at different locations.

Factors	WL (%)	L*
SP*		
1	3.91 (11.26) ± 0.29 E[1,2]	84.88 ± 0.12 A[3]
2	4.18 (11.72) ± 0.23 E	84.48 ± 0.16 B
3	5.26 (13.24) ± 0.16 D	83.92 ± 0.15 C
4	6.47 (14.71) ± 0.18 C	83.47 ± 0.14 D
5	7.24 (15.60) ± 0.15 B	84.97 ± 0.35 A
6	7.77 (16.19) ± 0.12 A	84.69 ± 0.47 AB
SLs*		
Ankara	5.84 (13.75) ± 0.27 ns[4]	84.98 ± 0.15 A
Taşköprü	5.77 (13.82) ± 0.17 ns	83.82 ± 0.14 B
MeJA*		
Control	5.28 (13.07) ± 0.30 C[2]	84.56 ± 0.15 A
10^{-3}	5.87 (13.89) ± 0.28 B	83.98 ± 0.26 B
10^{-5}	6.26 14.40) ± 0.24 A	84.67 ± 0.17 A
SP × SLs		
1 × Ankara	2.98 (9.84) ± 0.30 F,b[5]	85.22 ± 0.18 BC,a
2 × Ankara	4.22 (11.76) ± 0.39 E,a	84.92 ± 0.25 C,a
3 × Ankara	5.38 (13.38) ± 0.26 D,a	84.24 ± 0.24 D,a
4 × Ankara	6.71 (14.98) ± 0.35 C,a	83.66 ± 0.25 E,a
5 × Ankara	7.61 (16.00) ± 0.24 B,a	86.18 ± 0.25 A,a
6 × Ankara	8.13 (16.57) ± 0.15 A,a	85.67 ± 0.30 AB,a
1 × Taşköprü	4.83 (12.68) ± 0.22 D,a	84.53 ± 0.06 A,b
2 × Taşköprü	4.14 (11.69) ± 0.28 E,a	84.05 ± 0.08 AB,b
3 × Taşköprü	5.14 (13.09) ± 0.21 D,a	83.60 ± 0.12 BC,b
4 × Taşköprü	6.22 (14.45) ± 0.10 C,b	83.28 ± 0.13 C,a
5 × Taşköprü	6.87 (15.19) ± 0.09 B,b	83.75 ± 0.30 BC,b
6 × Taşköprü	7.42 (15.81) ± 0.09 A,b	83.71 ± 0.79 BC,b
SP × MeJA		
1 × control	3.20 (10.10) ± 0.56 E,b[6]	84.97 ± 0.23 AB,a
2 × control	3.33 (10.49) ± 0.22 E,c	84.35 ± 0.18 BC,a
3 × control	4.86 (12.71) ± 0.30 D,b	84.05 ± 0.08 CD,ab
4 × control	5.86 (14.01) ± 0.20 C,c	83.53 ± 0.12 D,ab
5 × control	6.90 (15.22) ± 0.25 B,b	85.44 ± 0.53 A,a
6 × control	7.52 (15.92) ± 0.13 A,a	84.99 ± 0.20 AB,a
1×10^{-3}	4.18 (11.79) ± 0.17 D,a	84.98 ± 0.28 A,a
2×10^{-3}	3.90 (11.37) ± 0.24 D,b	84.43 ± 0.30 A,a
3×10^{-3}	5.14 (13.09) ± 0.30 C,b	83.44 ± 0.19 BC,b
4×10^{-3}	6.56 (14.83) ± 0.30 B,b	82.98 ± 0.17 C,b
5×10^{-3}	7.59 (15.98) ± 0.30 A,a	84.38 ± 0.66 A,b
6×10^{-3}	7.86 (16.28) ± 0.20 A,a	83.70 ± 1.34 B,b
1×10^{-5}	4.35 (11.89) ± 0.60 E,a	84.67 ± 0.12 BC,a

Table 1. (Continued).

2 × 10^{-5}	5.31 (13.31) ± 0.21 D,a	84.67 ± 0.37 BC,a
3 × 10^{-5}	5.78 (13.91) ± 0.11 C,a	84.28 ± 0.34 CD,a
4 × 10^{-5}	6.98 (15.30) ± 0.31 B,a	83.91 ± 0.28 D,a
5 × 10^{-5}	7.22 (15.59) ± 0.18 B,ab	85.08 ± 0.64 AB,a
6 × 10^{-5}	7.94 (16.36) ± 0.27 A,a	85.40 ± 0.41 A,a
SLs × MeJA		
Ankara × control	4.93 (12.52) ± 0.51 B,b[7]	84.83 ± 0.26 B,a
Ankara × 10^{-3}	6.26 (14.35) ± 0.42 A,a	84.88 ± 0.33 AB,a
Ankara × 10^{-5}	6.33 (14.40) ± 0.44 A,a	85.23 ± 0.17 A,a
Taşköprü × control	5.62 (13.63) ± 0.31 B,a	84.28 ± 0.12 A,b
Taşköprü × 10^{-3}	5.49 (13.43) ± 0.35 B,b	83.08 ± 0.30 B,b
Taşköprü × 10^{-5}	6.20 (14.39) ± 0.20 A,a	84.10 ± 0.23 A,b
SP × SLs × MeJA		
1 × Ankara × control	1.96 (8.03) ± 0.15 E,c,b[8]	85.42 ± 0.22 B,a,a
2 × Ankara × control	2.91 (9.81) ± 0.23 D,c,b	84.50 ± 0.33 BC,a,a
3 × Ankara × control	4.45 (12.12) ± 0.26 C,b,b	84.16 ± 0.06 CD,ab,a
4 × Ankara × control	5.42 (13.49) ± 0.12 B,b,b	83.38 ± 0.22 D,b,a
5 × Ankara × control	7.11 (15.44) ± 0.50 A,b,a	86.48 ± 0.44 A,a,a
6 × Ankara × control	7.75 (16.16) ± 0.18 A,a,a	85.03 ± 0.37 BC,b,a
1 × Ankara × 10^{-3}	3.94 (11.44) ± 0.11 D,a,b	85.43 ± 0.43 B,a,a
2 × Ankara × 10^{-3}	4.33 (12.00) ± 0.25 D,b,a	84.84 ± 0.52 B,a,a
3 × Ankara × 10^{-3}	5.74 (13.85) ± 0.32 C,a,a	83.52 ± 0.35 C,b,a
4 × Ankara × 10^{-3}	7.13 (15.48) ± 0.33 B,a,a	83.10 ± 0.37 C,b,a
5 × Ankara × 10^{-3}	8.21 (16.64) ± 0.29 A,a,a	85.76 ± 0.47 AB,a,a
6 × Ankara × 10^{-3}	8.20 (16.63) ± 0.30 A,a,a	86.67 ± 0.17 A,a,a
1 × Ankara × 10^{-5}	3.06 (10.04) ± 0.35 D,b,b	84.81 ± 0.22 B,a,a
2 × Ankara × 10^{-5}	5.43 (13.45) ± 0.41 C,a,a	85.42 ± 0.38 AB,a,a
3 × Ankara × 10^{-5}	5.95 (14.11) ± 0.16 C,a,a	85.05 ± 0.07 B,a,a
4 × Ankara × 10^{-5}	7.59 (15.98) ± 0.30 B,a,a	84.50 ± 0.17 B,a,a
5 × Ankara × 10^{-5}	7.51 (15.90) ± 0.20 B,ab,a	86.30 ± 0.47 A,a,a
6 × Ankara × 10^{-5}	8.46 (16.90) ± 0.19 A,a,a	85.33 ± 0.43 AB,b,a
1 × Taşköprü × control	4.44 (12.16) ± 0.16 D,b,a	84.52 ± 0.10 AB,a,b
2 × Taşköprü × control	3.75 (11.17) ± 0.11 E,b,a	84.21 ± 0.18 AB,a,a
3 × Taşköprü × control	5.27 (13.25) ± 0.48 C,b,a	83.94 ± 0.14 AB,a,a
4 × Taşköprü × control	6.30 (14.54) ± 0.09 B,a,a	83.68 ± 0.01 B,a,a
5 × Taşköprü × control	6.69 (14.98) ± 0.18 AB,a,b	84.39 ± 0.40 AB,a,b
6 × Taşköprü × control	7.30 (15.68) ± 0.12 A,a,b	84.96 ± 0.24 A,a,a
1 × Taşköprü × 10^{-3}	4.42 (12.13) ± 0.27 C,b,a	84.54 ± 0.17 A,a,a
2 × Taşköprü × 10^{-3}	3.47 (10.72) ± 0.24 D,b,b	84.03 ± 0.19 AB,a,a
3 × Taşköprü × 10^{-3}	4.55 (12.32) ± 0.07 C,b,b	83.35 ± 0.22 BC,a,a
4 × Taşköprü × 10^{-3}	6.00 (14.17) ± 0.19 B,a,b	82.86 ± 0.05 C,a,a
5 × Taşköprü × 10^{-3}	6.97 (15.31) ± 0.06 A,a,b	83.00 ± 0.28 C,b,b
6 × Taşköprü × 10^{-3}	7.53 (15.92) ± 0.09 A,a,b	80.72 ± 0.26 D,b,b

Table 1. (Continued).

1 × Taşköprü × 10^{-5}	5.64 (13.74) ± 0.13 CD,a,a	84.54 ± 0.11 B,a,a
2 × Taşköprü × 10^{-5}	5.19 (13.16) ± 0.23 D,a,a	83.92 ± 0.05 BC,a,b
3 × Taşköprü × 10^{-5}	5.61 (13.70) ± 0.11 CD,a,b	83.51 ± 0.07 C,a,b
4 × Taşköprü × 10^{-5}	6.37 (14.62) ± 0.21 BC,a,b	83.32 ± 0.17 C,a,b
5 × Taşköprü × 10^{-5}	6.94 (15.27) ± 0.19 AB,a,b	83.87 ± 0.63 BC,ab,b
6 × Taşköprü × 10^{-5}	7.42 (15.80) ± 0.27 A,a,b	85.47 ± 0.82 A,a,a
Significant effects		
SP	0.000[9]	0.000
SLs	0.554	0.000
MeJA	0.000	0.000
SP × SLs	0.000	0.000
SP × MeJA	0.000	0.006
SLs × MeJA	0.000	0.000
SP × SLs × MeJA	0.003	0.000

[*]SP: storage period (months), SLs: storage locations (Ankara and Taşköprü), MeJA: Methyl jasmonate treatments (10^{-3} and 10^{-5} M).
[1]Data presented as mean (arcsin value) ± standard error of mean (SEM).
[2]Letters show differences within each experimental factor at P ≤ 0.05 error level, according to Duncan's multiple range test.
[3]Data presented as mean ± standard error of mean (SEM).
[4]ns: nonsignificant.
[5]Capital letters show differences among storage periods in each location, lower letters show differences between locations in each storage period.
[6]Capital letters show differences among storage periods in each MeJA doses, lower letters show differences between the MeJA doses in each storage period.
[7]Capital letters show differences between MeJA doses in each storage location, lower letters show differences between storage locations in each MeJA doses at P ≤ 0.05 error level according to Duncan's multiple range test.
[8]First capital letters show differences among storage period in each MeJA dose, first lower letters show differences among storage locations in each storage period, second lower letters show differences between MeJA doses in each storage locations at P ≤ 0.05 error level according to Duncan's multiple range test.
[9]P values calculated by variance analysis.

this parameter were reported by Veríssimo et al. (2010) and Lu et al. (2011), who indicated that TPC values increased during the storage period of garlic. Based on current results, the differences in data obtained herein could be due to genotype and pre and postharvest conditions. In the current study, samples stored in Ankara had higher average TPC than those of Taşköprü (26.12 and 25.86 mg GAE $100g^{-1}$). Additionally, we observed a positive impact of both MeJA doses, by preventing reduction in TPC compared to controls (Table 2) and 10^{-3} M MeJA treatment (26.56 mg GAE $100g^{-1}$) in particular enhanced the best protective effect among other treatments. Maintaining of TPC could be closely related with phenylalanine ammonia-lyase (PAL) activity, which was induced by MeJA (Khan et al., 2018).

Statistical calculations showed significant impact of both SP and MeJA treatments (P ≤ 0.05) on maintaining AOC in stored garlic bulbs (Table 3). AOC levels of garlic bulbs decreased during the storage period and this trend was particularly clear after the 4th storage month (64.63% I) (Table 3). This situation was consistent with the previous findings of Veríssimo et al. (2010), who pointed out that longer storage period promotes a decrease of AOC level in garlic cloves. Queiroz et al. (2009) mentioned that the decrease in AOC of garlic cloves during the storage period could be caused by the storage temperature rather than the storage period. The decrease of AOC level herein, associated with storage period, may depend on a decrease of antioxidant vitamins such as vitamin C, phenols, and thiols as sulphur compounds, as mentioned earlier, reported in onions by Yang et al. (2004). Some previous reports also stated that variation of AOC level in garlic during storage is due to its extraction method (Bozin et

Table 2. Effects of MeJA treatments on the SSC, firmness, TA, and TPC values of garlic bulbs stored for 6 months at different locations.

Factors	SSC (%)	Firmness (N)	TA (citric acid %)	TPC (mg GAE $100g^{-1}$)
SP*				
1	37.97 ± 0.14 E[1,2]	11.35 ± 0.06 A	0.67 ± 0.02 F	28.38 ± 0.21 A
2	38.33 ± 0.42 DE	10.78 ± 0.10 A	0.77 ± 0.01 E	27.68 ± 0.26 B
3	38.71 ± 0.42 CD	10.97 ± 0.52 A	0.87 ± 0.03 D	26.97 ± 0.22 C
4	39.21 ± 0.33 C	9.81 ± 0.11 B	0.94 ± 0.02 C	25.00 ± 0.34 D
5	39.85 ± 0.27 B	9.00 ± 0.11 C	1.05 ± 0.02 B	24.35 ± 0.19 E
6	40.77 ± 0.23 A	8.00 ± 0.09 D	1.17 ± 0.02 A	23.56 ± 0.19 F
SLs*				
Ankara	39.08 ± 0.21 ns[3]	10.03 ± 0.24 ns	0.94 ± 0.02 A[3]	26.12 ± 0.27 A
Taşköprü	39.20 ± 0.23 ns	9.04 ± 0.16 ns	0.89 ± 0.02 B	25.86 ± 0.28 B
MeJA*				
Control	39.71 ± 0.18 A[2]	10.11 ± 0.33 ns	0.90 ± 0.03 ns	25.49 ± 0.35 C
10^{-3}	38.08 ± 0.29 B	9.66 ± 0.21 ns	0.92 ± 0.02 ns	26.56 ± 0.27 A
10^{-5}	39.63 ± 0.23 A	10.18 ± 0.19 ns	0.91 ± 0.03 ns	25.91 ± 0.37 B
SP × SLs				
1 × Ankara	38.00 ± 0.25 ns	11.34 ± 0.10 ns	0.66 ± 0.02 ns	28.67 ± 0.21 A,a[4]
2 × Ankara	38.41 ± 0.55 ns	10.71 ± 0.14 ns	0.78 ± 0.02 ns	27.25 ± 0.47 B,b
3 × Ankara	38.61 ± 0.62 ns	11.43 ± 1.06 ns	0.93 ± 0.04 ns	26.77 ± 0.34 B,a
4 × Ankara	39.13 ± 0.48 ns	9.72 ± 0.12 ns	1.00 ± 0.03 ns	25.80 ± 0.47 C,a
5 × Ankara	39.75 ± 0.36 ns	8.98 ± 0.13 ns	1.06 ± 0.02 ns	24.53 ± 0.38 D,a
6 × Ankara	40.57 ± 0.35 ns	8.00 ± 0.13 ns	1.20 ± 0.04 ns	23.67 ± 0.34 E,a
1 × Taşköprü	37.94 ± 0.14 ns	11.35 ± 0.06 ns	0.68 ± 0.03 ns	28.08 ± 0.34 A,b
2 × Taşköprü	38.25 ± 0.66 ns	10.86 ± 0.15 ns	0.76 ± 0.02 ns	28.10 ± 0.19 A,a
3 × Taşköprü	38.82 ± 0.59 ns	10.51 ± 0.11 ns	0.81 ± 0.03 ns	27.18 ± 0.29 B,a
4 × Taşköprü	39.30 ± 0.47 ns	9.90 ± 0.18 ns	0.88 ± 0.02 ns	24.20 ± 0.32 C,b
5 × Taşköprü	39.95 ± 0.41 ns	9.02 ± 0.18 ns	1.03 ± 0.04 ns	24.17 ± 0.10 C,a
6 × Taşköprü	40.97 ± 0.32 ns	8.01 ± 0.15 ns	1.15 ± 0.03 ns	23.46 ± 0.19 D,a
SP × MeJA				
1 × control	38.13 ± 0.20 D,a[5]	11.40 ± 0.06 ns	0.66 ± 0.04 ns	28.26 ± 0.14 A,b
2 × control	39.60 ± 0.21 BC,a	10.95 ± 0.07 ns	0.78 ± 0.03 ns	27.45 ± 0.45 B,b
3 × control	40.15 ± 0.06 ABC,a	10.65 ± 0.13 ns	0.88 ± 0.06 ns	26.44 ± 0.13 C,b
4 × control	40.23 ± 0.16 AB,a	10.13 ± 0.08 ns	0.91 ± 0.03 ns	24.08 ± 0.50 D,b
5 × control	39.16 ± 0.13 C,b	9.48 ± 0.10 ns	1.01 ± 0.04 ns	23.86 ± 0.11 D,b
6 × control	41.03 ± 0.49 A,a	8.08 ± 0.19 ns	1.18 ± 0.04 ns	22.87 ± 0.08 E,b
1 × 10^{-3}	38.13 ± 0.15 C,a	11.51 ± 0.08 ns	0.73 ± 0.03 ns	27.78 ± 0.40 AB,b
2 × 10^{-3}	36.31 ± 0.44 D,b	10.71 ± 0.19 ns	0.78 ± 0.03 ns	28.22 ± 0.27 A,a
3 × 10^{-3}	36.38 ± 0.11 D,b	10.06 ± 0.09 ns	0.85 ± 0.02 ns	27.49 ± 0.30 B,a
4 × 10^{-3}	37.46 ± 0.18 C,b	9.38 ± 0.07 ns	0.95 ± 0.02 ns	26.26 ± 0.63 C,a
5 × 10^{-3}	39.16 ± 0.31 B,b	8.56 ± 0.08 ns	1.06 ± 0.04 ns	25.19 ± 0.36 D,a
6 × 10^{-3}	41.03 ± 0.23 A,a	7.73 ± 0.07 ns	1.15 ± 0.04 ns	24.44 ± 0.29 E,a
1 × 10^{-5}	37.65 ± 0.33 D,a	11.13 ± 0.10 ns	0.63 ± 0.03 ns	29.09 ± 0.30 A,a
2 × 10^{-5}	39.08 ± 0.55 C,a	10.70 ± 0.24 ns	0.78 ± 0.03 ns	27.36 ± 0.60 B,b

Table 2. (Continued).

3 × 10^{-5}	39.61 ± 0.36 BC,a	12.20 ± 1.52 ns	0.88 ± 0.06 ns	26.99 ± 0.54 B,ab
4 × 10^{-5}	39.95 ± 0.37 BC,a	9.91 ± 0.22 ns	0.96 ± 0.07 ns	24.67 ± 0.11 C,b
5 × 10^{-5}	41.23 ± 0.22 A,a	8.56 ± 0.08 ns	1.06 ± 0.05 ns	23.99 ± 0.16 CD,b
6 × 10^{-5}	40.26 ± 0.44 B,a	7.73 ± 0.07 ns	1.20 ± 0.04 ns	23.38 ± 0.17 D,b
SLs × MeJA				
Ankara × control	39.75 ± 0.23 ns	10.15 ± 0.28 ns	0.94 ± 0.05 B,a[6]	25.60 ± 0.47 B,a
Ankara × 10^{-3}	38.05 ± 0.39 ns	9.67 ± 0.31 ns	0.88 ± 0.03 C,b	27.23 ± 0.32 A,a
Ankara × 10^{-5}	39.43 ± 0.35 ns	10.26 ± 0.60 ns	1.00 ± 0.05 A,a	25.51 ± 0.51 B,b
Taşköprü × control	39.68 ± 0.28 ns	10.07 ± 0.26 ns	0.87 ± 0.04 B,b	25.38 ± 0.54 C,a
Taşköprü × 10^{-3}	39.82 ± 0.32 ns	10.10 ± 0.29 ns	0.96 ± 0.04 A,a	25.90 ± 0.40 B,b
Taşköprü × 10^{-5}	38.11 ± 0.45 ns	9.65 ± 0.31 ns	0.83 ± 0.04 B,b	26.31 ± 0.53 A,a
Significant effects				
SP	0.000[7]	0.000	0.000	0.000
SLs	0.420	0.634	0.003	0.031
MeJA	0.000	0.051	0.770	0.000
SP × SLs	0.927	0.532	0.114	0.000
SP × MeJA	0.000	0.137	0.641	0.000
SLs × MeJA	0.475	0.957	0.000	0.000
SP × SLs × MeJA	0.979	0.517	0.223	0.165

[*]SP: storage period (months), SLs: storage locations (Ankara and Taşköprü),
MeJA: Methyl jasmonate treatments (10^{-3} and 10^{-5} M).
[1]Data presented as mean ± SEM.
[2]Letters show differences within each experimental factor at P ≤ 0.05 error level, according to Duncan's Multiple Range test.
[3]ns: nonsignificant.
[4]Capital letters show differences among storage periods in each location, lower letters show differences between locations in each storage period.
[5]Capital letters show differences among storage periods in each MeJA doses, lower letters show differences between the MeJA doses in each storage period.
[6]Capital letters show differences between MeJA doses in each storage location, lower letters show differences between storage locations in each MeJA doses at P ≤ 0.05 error level according to Duncan's multiple range test.
[7]P values calculated by variance analysis.

al., 2008). The higher AOC values (66.88% I) were found in 10^{-5} M MeJA compared to 10^{-3} M MeJA (63.09% I) (Table 3). Our results are compatible with some reports on horticultural crops which mentioned that MeJA treatments enhanced and maintained antioxidant capacity (Khan et al., 2018; Akan et al., 2019).

In garlic bulbs, SP was the main factor affecting vitamin C content in the current research (P ≤ 0.05). During the storage period, vitamin C content in samples regularly decreased from 54.19 to 32.78 mg kg^{-1} (Table 3). Some previous reports on peeled garlic cloves (Dronachari et al., 2010; Akan et al., 2019) and bulbs (Cho et al., 1984; Sharma et al., 2020) exhibited similar changes in vitamin C content during storage period. However, the effect of both MeJA and SLs on this attribute were negligible for whole storage duration. Conversely, previous studies reported that MeJA treatment inhibited the decrease in ascorbic acid in some horticultural products (Khan et al., 2018).

Garlic flavor is due to the formation of organosulfur compounds when the main odorless precursor alliin is converted by the enzyme alliinase to allicin. Allicin is the main precursor of the pungent flavor and one of the most biologically active compounds in garlic (Arzanlou and Bohlooli, 2010). According to Kacjan Marsic et al. (2019), preharvest factors, for example; water stress, light intensity and exposure time, and temperatures significantly affect biosynthesis of organosulfur compounds in *Allium* species. Considering the high instability of organosulfur compounds, storage under optimum storage conditions is crucial to maintain the high quality of garlic bulbs due to its allicin content dependant on storage temperature and atmosphere composition (Cantwell 2000; Martins et al.,

Table 3. Effects of MeJA treatments on the AOC, vitamin C, and allicin content values of garlic bulbs stored for 6 months at different locations.

Factors	AOC (inhibition %)	Vitamin C (mg kg^{-1})	Allicin (mg kg^{-1})
SP*			
1	70.25 ± 1.20 A[1,2]	54.19 ± 1.87 A	23.45 ± 4.19 ns[3]
2	68.61 ± 1.77 A	46.62 ± 2.06 B	24.89 ± 3.86 ns
3	68.81 ± 1.60 A	40.64 ± 2.91 BC	22.75 ± 6.79 ns
4	64.63 ± 1.57 B	39.44 ± 1.73 CD	21.77 ± 6.06 ns
5	59.86 ± 0.65 C	36.58 ± 2.25 CD	30.16 ± 7.03 ns
6	57.31 ± 0.34 C	32.78 ± 1.39 D	36.46 ± 5.93 ns
SLs*			
Ankara	65.50 ± 1.09 ns	41.36 ± 1.45 ns	21.97 ± 2.92 B[2]
Taşköprü	64.32 ± 0.87 ns	42.06 ± 1.60 ns	31.42 ± 3.62 A
MeJA*			
Control	64.77 ± 1.05 AB[2]	42.36 ± 2.05 ns	28.59 ± 3.55 ns
10^{-3}	63.09 ± 1.27 B	40.22 ± 1.98 ns	31.37 ± 4.50 ns
10^{-5}	66.88 ± 1.25 A	42.54 ± 1.52 ns	19.62 ± 3.99 ns
Significant effects			
SP	0.000[4]	0.000	0.397
SLs	0.250	0.716	0.038
MeJA	0.012	0.541	0.131
SP × SLs	0.220	0.858	0.183
SP × MeJA	0.885	0.989	0.169
SLs × MeJA	0.156	0.620	0.565
SP × SLs × MeJA	0.233	0.955	0.811

*SP: storage period (months), SLs: storage locations (Ankara and Taşköprü), MeJA: Methyl jasmonate treatments (10^{-3} and 10^{-5} M).
[1]Data presented as mean ± SEM.
[2]Letters show differences within each experimental factor at $P \leq 0.05$ error level, according to Duncan's multiple range test.
[3]ns: nonsignificant.
[4]P values calculated by variance analysis.

2016). Little is known exactly about the change of allicin content of garlic during storage conditions. In present study, SLs ($P \leq 0.05$) was significantly effective on allicin content of stored garlic bulbs and samples stored in Taşköprü (31.42 mg kg^{-1}) had higher allicin content than samples stored in Ankara location (21.97 mg kg^{-1}) (Table 3). This situation is thought to be because of low storage temperatures and RH in Taşköprü. In our study, average allicin values of garlic bulbs showed an insignificant increase especially after the 5th month. The results are consistent with Sharma et al. (2020), who found that allicin content decreased until 135 days and then increased thereafter till 195 days. On the other hand, Veríssimo et al. (2010) reported that allicin content in the garlic decreased during the storage period. Earlier studies pointed out significant increases in allicin content of garlic (Sukkaew and Tira-Umphon, 2012; Akan et al., 2019; Kacjan Marsic et al., 2019). Li et al. (2008) enounced increase in allicin content during storage period by maximum activity of g-glutamyl transpeptidase (GTP), regulating the final step of allicin synthesis, at 4 °C. Lancaster and Shaw (1991) mentioned a five fold increase in GTP activity during sprouting in onion. In contrast to aforementioned researchers, Arzanlou and Bohlooli (2010), and Torun (2015) claimed a decrease in allicin content during storage period.

4. Conclusions

Proper garlic storage is of utmost importance to meet quality requirements of global and domestic markets, and to ensure sufficient raw material availability for the food processing industry. According to our results, MeJA treatment at 10^{-5} M significantly delayed color changes and enhanced SSC and AOC levels, and 10^{-3} M MeJA treatment maintained WL and TPC in garlic bulbs during the storage period. In addition, the combination effect of MeJA and storage locations was observed to retard an increasing of TA in stored garlic bulbs. Higher allicin content in samples stored in the warehouse at the Taşköprü location could suggest that storage of garlic at this location could be preferred in order to maintain the health benefits of garlic cloves to prevent postharvest losses. In addition, firmness and vitamin C content decreased as the storage period increased. Overall, exogenous MeJA treatment could be a new candidate for keeping postharvest quality in stored garlic bulbs. We hope that this study will help to decrease quality losses and provide potential knowledge for further researches.

Acknowledgments/Disclaimers/Conflict of interest
This research was financially supported by Scientific Research Projects Unit at Ankara University (11Y4347001 project number). This research includes the first part data obtained by this research project. The authors thank Prof. Dr. Mohsen Arzanlou, Ardabil University of Medical Sciences, Department of Microbiology, Parasitology, and Immunology, Ardabil, Iran, for his kind sharing of knowledge on allicin analysis. The authors declare that they have no conflict of interest.

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