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RESEARCH ARTICLE

Use of modified atmosphere packaging to manage quality of green garlic leaves during cold storage period

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ABSTRACT

Green garlic leaves are consumed as fresh and cooked in Turkey and in some part of the world such as Asia, America and Africa. This crop could be considered as a promising export product in Turkey's exportation volume. For this reason, we investigated how different package materials such as low-density polyethylene (LDPE) and closed polypropylene transparent boxes (CPTB) maintain some quality parameters of green garlic (*Allim sativum* L.) leaves. For that purpose, garlic leaves were stored at 10 °C and 80 ± 5% relative humidity for 12 days after cutting, pre-cooling and packaging. Weight loss (WL), soluble solids content (SSC), titratable acidity (TA), chlorophyll content as SPAD reading, visual quality (VQ), color, total phenolic content (TPC) and total antioxidant capacity (TAC) were measured at 3, 6, 9 and 12 days during storage period. Our results indicated that both packaging materials significantly maintained ($P \leq 0.05$) WL, TA, chlorophyll content, VQ and TPC compared to controls (unpacked samples). Pearson Correlation tests showed that WL, color (L^*, b^*), TA and TAC could be used as marker to determine storage life of green garlic leaves. In addition, CPTB package is more effective in maintaining quality of green garlic leaves during cold storage.

Keywords: *Allium sativum* L.; Color; MAP; Total antioxidant capacity

INTRODUCTION

Garlic (*Allium sativum* L.) belongs to the family of the *Alliaceae* and it has been consumed for centuries. Harvesting of the garlic at early stage when the bulb is not completely form, crop is called 'fresh garlic' (Akan et al., 2019a). Based on Common Quality Standard for Garlic Regulation, this product is refers to 'fresh garlic leaves' or 'green garlic' (Anonymous, 2019a). Essentially, green garlic is very similar to green onion. Many people, in North Asia, Middle East, South Africa, Europe, North and Central America, Southeast Asia, have used green garlic leaves for daily diets because of its special taste (Upadhyay, 2016). Green garlic leaves are preferred for roasting, salads and soups as well as meat dishes in Central Anatolia, Eastern Anatolia and Mediterranean cuisine.

Green garlic is economically important crop for Turkey's export. In the last four years, green garlic export of Turkey increased more than thousands fold and reached 110.8 tons with an export income of 126 thousand US dollars. It seems that this crop can be considered as a promising export product in the future (TSI, 2020).

In terms of nutritional value, green garlic contains, 9.5 mg $100g^{-1}$ glucose, 15.6 mg $100g^{-1}$ fructose, 4.6 mg $100g^{-1}$ sucrose, 7.0% moisture, 7.6% crude protein, 1.8% crude oil, 6.6% ash, 9.9% fiber and 77.0% total carbohydrate. The main minerals are K (1.14 mg $100g^{-1}$), Ca (679.05 mg $100g^{-1}$), P (342.09 mg $100g^{-1}$) and Na (130.42 mg $100g^{-1}$). The most common amino acids are methionine (1.16 mg $100g^{-1}$), cysteine (1.13 mg $100g^{-1}$), proline (781.10 mg $100g^{-1}$) and glutamic acid (605.70 mg $100g^{-1}$) (Lee et al., 2005). Nambiar and Sharma (2014) observed that green garlic is a rich source of β-carotene 2376.97 μg $100g^{-1}$ and total carotene 6707.23 μg $100g^{-1}$. Green garlic leaves like garlic bulbs, contain low amounts of flavonoids, acidic compounds and many sulfur compounds such as diallyl sulfate, alliin, ajoen, allicin (Khuda-Bukhsh et al., 2014). Arzanlou and Bohlooli (2010) have reported that

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green garlic leaves could be healthy because of its allicin content (0.26 mg mL^{-1}). Edris and Fadel (2002) determined essential oils such as diallyl trisulfide (32.32%), diallyl disulfide (31.35%) and methyl allyl trisulfide (11.40%) in green leaves of Egyptian garlics. Furthermore, green garlic is a powerful antidiabetic and cardiovascular agent that regulates insulin levels and reduces extra lipid concentration. It has hepatoprotective, immunomodulation and anti-inflammatory effects, chemopreventive activities on cancer cells (González et al., 2011; Batcioglu et al., 2012; Chu et al., 2013; Jin et al., 2013; Khatua et al., 2013).

In recent years, consumers have tended to reach fresh, healthy, and ready to cook foods, fresh-cut products (Memon et al., 2018). For fresh-cut foods, minimal processing used to keep the plant tissues and surfaces free from pathogen growth and this is the most important stage for keeping quality and marketing value (Fan et al., 2003). Like green onion, green garlic highly perishable product so it needs minimal processing for ready to use. In green onions, process begins with trimming leaves, cutting roots and removing all parts of the compressed stem and the last product consists of green leaf rings (Park et al., 1998; Hong et al., 2000b). By the way, some defects can occur in fresh-cut green onion include opening of rings and a high percentage sheathing of leaf bases (white stalks) (Fan et al., 2003). During minimal processing, tissue and cell integrity damage limits the shelf life of minimally processed products. Firstly, careless cutting causes undesired physiological and biochemical changes such as increase in polyphenol oxidase (PPO) activity, respiration rate, microbial growth and physical abuse. Secondly, unsuitable environmental factors such as high temperature, low relative humidity (RH) and non-optimal gas concentration increase the speed of these changes. As a result, all of them reveal quality losses in color, flavour and texture of minimally processed products (Kim et al., 1993; Chau and Talasila, 1994; Hong and Kim, 2004).

As in green onion, important quality markers of green garlic are freshness and hygiene, free from mechanical damage, smooth and sound minimal cutting, firmness of the neck, lightness (fully green color) (Anonymous, 2005). Hong et al. (2000b) considered inner leaf extension as main quality marker in green onion. Inner leaf extension refers to as 'telescoping' by Cantwell et al. (2001). The main reason of this injury is inattentive root cutting during minimal process. Inner leaf extension causes a rapid deterioration of the overall market quality of product, reducing its appearance value (Ragaret et al., 2004). Common quality standards in garlic are tightness, firmness, brightness, free from damage and decay (Anonymous, 2019a). The storage conditions of green garlic are quite different from garlic bulbs. While garlic bulbs can be stored up to 9 months under -1-0 °C temperature and 60-70% RH conditions (Cantwell and Suslow, 2002), green garlic can be stored up to 3-4 weeks under 0 °C temperature and 95-100% RH conditions (Goldy, 2000).

Modified atmosphere packaging (MAP) has a critical role in reduce leaf extension and root growth, delaying leaf curvature and decrease chlorophyll content loss in green onion depending on packaging material (Hong et al., 2000a; Li, 2001; Frezza et al., 2011; Viskelis et al., 2012). Hong and Kim (2004) investigated that the effects of different packages on bunched green onion quality during storage. The authors found that moderate vacuum packaging with a gas-permeable plastic film gave better quality on bunched onions, delaying microbial decay and provide visual sensory aspects, as compared with the other packages. Gonzáles et al. (2012) reported that vacuum packaging at 4 °C increased the storability of green onions. Moreover, Shehata et al. (2017) found that dipping green onion in hot water at 55 °C for 1 min and then stored at 5% O_2 + 5% CO_2 MAP were the most effective treatment for reducing decay, discoloration, maintaining high chlorophyll content, controlling leaf extension, reduce leaf curvature and root growth and excellent visual quality at 0 °C + 2 days and at 10 °C for 20 days.

Up to date, there are very limited data on quality of green garlic leaves during storage and marketing period (Akan et al., 2019a). That's why, in this study, we aimed to investigate the use of MAP to keep the quality of green garlic leaves under 10 °C temperature.

MATERIALS AND METHODS

Materials

Green garlics (*Allium sativum* L.) were harvested from the Bala District of Ankara Province (39° 27´ 3" N, 33° 3´ 53 E, 1050 m in elevation) Central Anatolia of Turkey in 2019. Then, experimentally uniform plants were selected and transported to Postharvest Laboratory at Ankara University, Faculty of Agriculture Department of Horticulture.

Sample preparation, packaging and storage

After manually removing of outer leaves, bulbs were removed by cutting. All samples were cut in order to become the same length (25 cm) by a sharp knife. Then, leaves were washed with tap water and dried on papers at 20 ± 2 °C temperature and 31 ± 5% RH for 30 min. All samples were pre-cooled at 10 °C for 5 hours and then half of them packed in low-density polyethylene (LDPE) bags (36 × 24 cm size, 150 micron thickness) by using Packtech, PCS-200 (300W, 220/240V, 50/60 Hz) and the rest were packed in closed polypropylene transparent boxes (CPTB) under storage conditions. Green garlic samples (packaged, unpackaged (controls)) were stored at 10 °C and 80±5% RH for 12 days. Storage temperature was chosen based on previous reports on green onions (Hong and Kim, 2004; Kim et al., 2005; Shehata et al., 2017).

Quality assessments

For weight losses (WL), green garlic leaves were weighed using a digital scale with 0.01 g precision (Mettler Toledo) and results were calculated as a percentage of the initial weight. Overall visual quality was evaluated on a 1-9 scale by a trained panelist group of 8 persons with reference points of 9: excellent; 7: good; 5: fair; 3: poor and 1: unusable, based on discoloration and inner leaf extension or 'telescoping' level of samples (Hong et al., 2000b) (Figure 1). Color of green garlic leaves were measured using a CR-200 Minolta chromameter on CIE L^* a^* b^* color space system (L^*= 0 black and L^* = 100 white, a* (red-green) and b* (yellow-blue) (McGuire, 1992). ΔE* (total color difference) values are used to show time depended changes in color. When ΔE* is greater than 2.3, the difference in color is visible by naked eye (McGuire, 1992). Total chlorophyll content of green garlic leaves was measured with a SPAD reading chlorophyll meter (FieldScout CM 1000) and thirty SPAD values were obtained for each replication (Liu et al., 2012). Soluble solids content (SSC) was measured by a digital Abbe refractometer (Leica) in squeezed juice (AOAC, 1990). Titratable acidity (TA) was determined in squeezed juice using an automatic titrator (DL 50 Mettler Toledo) by titration with 0.1 N NaOH to an endpoint of 8.1 and results were expressed as citric acid percentage (Anonymous, 2019b). In order to detect total antioxidant capacity (TAC) and total phenolic content (TPC), a 10 g of tissue sample was used in each replication. Tissue sample were taken from bulk of each replication and kept at -80 °C until analysis. TPC in green garlic was determined by Folin Ciocalteu reagent as in Lu et al. (2011) and results were expressed as gallic acid equivalents (mg GAE $g^{-1}FW^{-1}$). TAC were determined as DPPH radical scavenging activity as in Brand-Williams et al. (1995) and presented as inhibition reflects of DPPH (Inhibition %, I%). The changes in absorbance values of the samples were determined at 517 nm wavelength in spectrophotometer (Shimadzu UV/VIS).

Experimental design and statistical analyses

The research was carried out using green garlic leaves with three replications and each replication included one modified atmosphere packed samples. Each package consisted of three garlics in order to meet consumer package requirement. This experiment was set as randomized experimental design. Two-way variance analysis (ANOVA) was applied to data by MINITAB 17 (Trial version) program at the error level $P \leq 0.05$. Significant differences were checked by Duncan's Multiple Range Test in MSTAT-C at $P \leq 0.05$ error level. Storage periods (SP) and package materials (PM) were considered as depended variables. ArcSin transformations were applied to weight loss data. Moreover, in order to determine possible relationships among the parameters investigated in this research, data were subjected to Pearson correlation analyses at $P \leq 0.05$ error level.

RESULTS AND DISCUSSION

Weight loss (WL) is the main indicator for market quality of fresh products. The effects of SP × PM (P = 0.000)

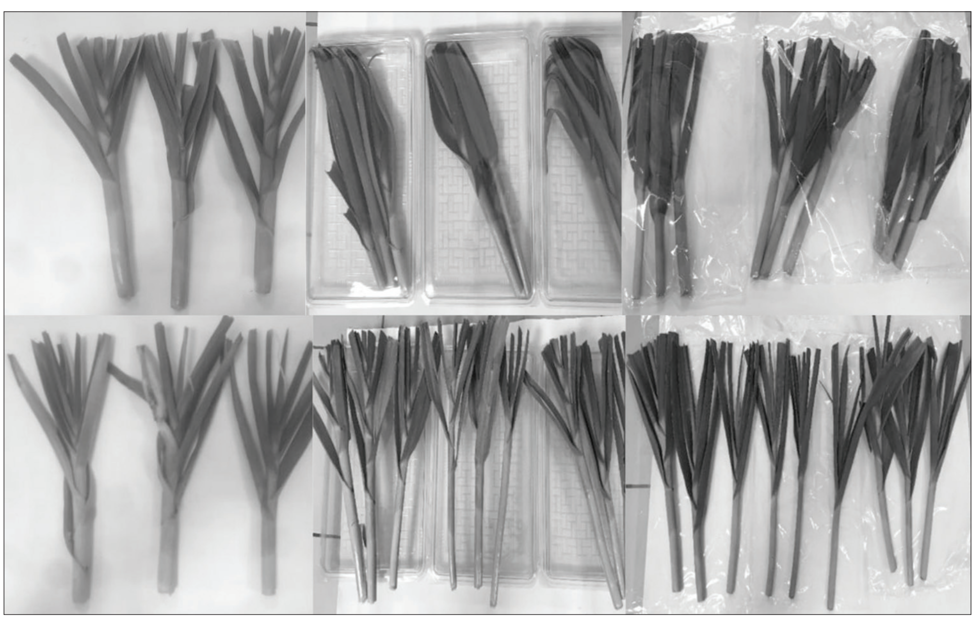

Fig 1. Appearance of green garlic leaves on 0th day (upside) and after 12 days storage at 10°C, 75.85% RH conditions (down side). (a) controls, (b) CPTB packed samples (c) LDPE packed samples.

on the WL values of garlic leaves were significant (P ≤ 0.05) (Table 1). In general, WL tended to increase in all treatments during the entire storage period. WL values reached up to 12.46% in controls after 12 days. A promising result was also observed in packaging treatments (LDPE and CPTB) which had the lowest WL as 0.34% and 0.63% respectively, at the end of the storage period (P ≤ 0.05) (Table 1). Packaging delayed significantly (P ≤ 0.05) the weight losses of green garlic leaves compared to the control groups. That is possible to say that the effect of packaging on keeping of WL was significant during 12 days. Similar positive effects of MAP in green onions have been reported by Hong and Kim (2004), Frezza et al. (2011), and in green garlic leaves by Akan et al. (2019a). In the current study, we did not observe significant differences between the package materials at the end of the storage period of 12 days.

Visual quality (VQ) have an impact for consumer preference for horticultural crops. VQ was evaluated based on discoloration and inner leaf extension 'telescoping'. Rather than interactions of SP × PM (P = 0.232), significant differences in VQ points were observed for SP (P = 0.000) and PM (P = 0.002). VQ points gradually decreased by prolonging storage period in all treatments (Table 1) (Figure 1). The highest average VQ values were determined as 6.16 and 5.83 for LDPE and CPTB, respectively (P ≤ 0.05). The average VQ value of controls was 1.66 after 12 days. Compared to the controls, MAP caused higher consumer preference in terms of color and inner leaf extension. Our results have supported by previous data on green garlic leaves (Akan et al., 2019a). Moreover, Fan et al. (2003) also mentioned that MAP maintained VQ in green onions. Hong and Kim (2004) pointed out that a score of 6.0 for VQ could be a marker for the end of shelf life or marketability period in green onions and polyethylene and polypropylene package materials could extend the shelf-life over 14 days. Similarly, Frezza et al. (2011) stated that type of film and storage temperature effected VQ of green onions.

Table 1: Effect of different package materials on weight loss (WL) and visual quality (VQ) of green garlic leaves during a storage period of 12 days under 10°C, 75-85% RH conditions

Factors	WL (%)	VQ (1-9 point)
Storage periods (SP) (day)		
0	0.00 (0.00)±0.00[1]	9.00±0.00
3	1.23 (4.76)±0.56 D[2]	8.33±0.33 A
6	2.02 (6.33)±0.91 C	7.22±0.52 B
9	3.12 (7.91)±1.40 B	4.77±0.52 C
12	4.47 (9.51)±2.01 A	1.66±0.33 D
Package materials (PM)		
Control (-MAP)	7.57 (15.58)±1.03 A[2]	4.50±0.78 B
CPTB	0.34 (3.22)±0.05 B	5.83±0.93 A
LDPE	0.21 (2.58)±0.02 B	6.16±0.75 A
SP×PM		
3×control	3.50 (10.77)±0.16 D,a[3]	7.66±0.66 ns[4]
3×CPTB	0.11 (1.92)±0.03 A,b	9.00±0.00 ns
3×LDPE	0.08 (1.58)±0.03 A,b	8.33±0.66 ns
6×control	5.66 (13.75)±0.02 C,a	5.66±0.66 ns
6×CPTB	0.22 (2.70)±0.00 A,b	8.33±0.66 ns
6×LDPE	0.20 (2.53)±0.26 A,b	7.66±0.66 ns
9×control	8.69 (17.14)±0.36 B,a	3.66±0.66 ns
9×CPTB	0.42 (3.71)±0.00 A,b	4.33±0.66 ns
9×LDPE	0.25 (2.88)±0.01 A,b	6.33±0.66 ns
12×control	12.46 (20.65)±0.73 A,a	1.00±0.00 ns
12×CPTB	0.63 (4.54)±0.01 A,b	1.66±0.66 ns
12×LDPE	0.34 (3.32)±0.03 A,b	2.33±0.66 ns
Significant effects		
SP	0.000[5]	0.000
PM	0.000	0.002
SP×PM	0.000	0.232

[1]Data presented as mean (arcsin value)±standard error of 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]Capital letters show differences among storage periods for each packaging material, lower letters show differences between the packaging materials for each storage period ($P \leq 0.05$). [4]ns: no significant. [5]P values calculated by variance analysis

Results in Table 2 reveal that the effect of SP × PM on L* values (lightness) was not significant (P = 0.417), whereas SP (P = 0.000) and PM (P = 0.000) significantly affected L* values. By the end of the storage period, average L* values reached the highest (52.24). Our results in consistent with Hong and Kim (2004), Kim et al. (2005), Viskelis et al. (2012), Kasım and Kasım (2018) for green onions and Akan et al. (2019a) for green garlic leaves. In the current study, the L values of green garlic leaves in both MAP materials were lower than controls. However, among packaging materials CPTB (48.31) was higher than LDPE (46.04).

It was observed that, a* and b* yellowness increased linearly for control and treatments by prolonging of storage periods (Figure 1). For a* and b* values, SP × PM interactions (P = 0.286 and P = 0.185, respectively) were not significant, SP (P = 0.000) and PM (P = 0.000) individually effected these values (Table 2). During storage period, average a* and b* values tended to increase and the same trend was observed by Kasım et al. (2008), Frezza et al. (2011) and Kasım and Kasım (2018) in green onions. In the current study, controls showed significantly higher average a* and b* values and the lowest average values were observed in LDPE packed samples. This could be resulted from gas permeability of packaging materials and chlorophyll degradation.

ΔE* value represents overall color change during storage period. PM (P = 0.016) significantly affected this parameter (P ≤ 0.05) (Table 2). The lower values were calculated in MA-packed samples as 9.58 and 6.33 in CPTB and LDPE, respectively. However, the highest average ΔE* value was in controls (21.69). This could be revealed that MA-packaging caused less color change.

Table 2: Effect of different package materials on color parameters (L*, a*, b*, ∆E*) and chlorophyll content (SPAD) of green garlic leaves during a storage period of 12 days under 10°C, 75-85% RH conditions

Factors	L*	a*	b*	∆E*	SPAD
Storage periods (SP) (day)					
0	44.22±0.78[1]	-12.73±0.56	11.44±1.30	0.00±0.00	243.1±7.86
3	45.53±0.73^{D}[2]	-14.37±0.48^{C}	13.83±0.76^{D}	9.63±6.02^{ns}	228.4±7.63^{A}
6	47.24±0.80^{C}	-16.48±0.51^{B}	17.68±1.32^{C}	13.76±5.72^{ns}	170.3±10.30^{C}
9	49.82±1.36^{B}	-17.34±0.59^{B}	20.55±1.62^{B}	11.96±2.29^{ns}	195.6±5.91^{B}
12	52.24±1.40^{A}	-18.90±0.45^{A}	24.58±1.56^{A}	14.76±2.60^{ns}	215.2±15.40^{AB}
Package materials (PM)					
Control (-MAP)	51.78±1.38^{A}[2]	-18.11±0.61^{A}	22.91±1.74^{A}	21.69±5.43^{A}	180.7±13.80^{B}
CPTB	48.31±0.84^{B}	-16.73±0.64^{B}	18.53±1.44^{B}	9.58±1.55^{B}	218.2±6.54^{A}
LDPE	46.04±0.58^{C}	-15.48±0.44^{C}	16.04±0.97^{C}	6.33±1.19^{B}	208.3±8.14^{A}
SP×PM					
3×control	47.10±2.06^{ns}[4]	-15.47±1.25^{ns}	15.35±2.17^{ns}	21.70±18.00^{ns}	240.3±21.90^{A,a}[3]
3×CPTB	45.05±0.39^{ns}	-13.52±0.45^{ns}	12.48±0.41^{ns}	2.89±0.48^{ns}	222.7±2.03^{AB,a}
3×LDPE	44.43±0.31^{ns}	-14.13±0.06^{ns}	13.66±0.33^{ns}	4.26±0.30^{ns}	222.3±10.40^{AB,a}
6×control	49.60±1.20^{ns}	-18.18±0.43^{ns}	22.46±1.34^{ns}	28.50±15.00^{ns}	133.7±3.48^{C,b}
6×CPTB	47.24±0.64^{ns}	-16.46±0.17^{ns}	16.44±0.27^{ns}	7.86±0.46^{ns}	200.3±5.36^{B,a}
6×LDPE	44.87±0.58^{ns}	-14.79±0.35^{ns}	14.13±0.75^{ns}	4.90±0.87^{ns}	177.0±8.72^{C,a}
9×control	54.55±1.89^{ns}	-18.80±0.90^{ns}	25.83±1.86^{ns}	18.98±3.31^{ns}	184.0±11.00^{B,a}
9×CPTB	48.66±0.58^{ns}	-17.78±0.35^{ns}	20.19±0.93^{ns}	11.18±1.70^{ns}	208.7±11.30^{AB,a}
9×LDPE	46.26±0.39^{ns}	-15.44±0.59^{ns}	15.62±0.95^{ns}	5.72±2.21^{ns}	194.0±4.04^{BC,a}
12×control	55.85±2.73^{ns}	-19.97±0.54^{ns}	27.99±3.29^{ns}	17.50±7.17^{ns}	164.7±23.80^{BC,b}
12×CPTB	52.29±1.03^{ns}	-19.16±0.41^{ns}	24.99±1.32^{ns}	16.36±1.28^{ns}	241.0±17.50^{A,a}
12×LDPE	48.58±1.34^{ns}	-17.57±0.72^{ns}	20.75±1.83^{ns}	10.43±3.72^{ns}	240.0±8.08^{A,a}
Significant Effects					
SP	0.000[5]	0.000	0.000	0.834	0.000
PM	0.000	0.000	0.000	0.016	0.001
SP × PM	0.417	0.286	0.185	0.833	0.009

[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]Capital letters show differences among storage periods for each packaging material, lower letters show differences between the packaging materials for each storage period (P≤0.05). [4]ns: no significant. [5]P values calculated by variance analysis

SPAD values could reflect total chlorophyll content in plant tissues. SPAD values were changed based SP × PM interactions (P = 0.009) (Table 2). Generally, SPAD values showed fluctuations during storage period and after 12 days, controls showed significantly lower SPAD value (164.7) than CPTB (241.0) and LDPE (240.0) packed samples. Akan et al. (2019a) reported higher SPAD values for MA-packed green garlic samples. Furthermore, our results are compatible with a report by Kasım and Kasım (2018) in green onions. Also, Shehata et al. (2017) stated that the decrease in chlorophyll content could be attributed to the gradual destruction by chlorophyllase activity and transformation of chloroplasts to chromoplasts. Moreover, chlorophyll concentration was affected by type of film and storage temperature in green onions (Frezza et al., 2011) and in parsley (Park et al., 1999).

It was observed that there were interactive effects of SP and PM (P= 0.001) on SSC values of garlic leaves during storage for 12 days. During storage period, SSC showed fluctuations based on treatments (Table 3). Kasım and Kasım (2018) and Akan et al. (2019a) reported similar trend for SSC in stored green onions and in garlic leaves, respectively. In the current study, controls had significantly average higher SSC (16.32%) than CPTB (14.98%) and LDPE (14.19%) packed samples. At the end of the storage period, controls (15.47%) and CPTB-packed samples (15.60%) had very close SSC, while LDPE-packed samples (13.20%) showed significantly lower value (Table 3). This situation is thought to be due to rapid water loss in the control group (Akan et al., 2019a; Torun, 2015).

Titratable acidity (TA) content in the garlic leaves were significantly influenced by SP × PM interactions (P = 0.000) (Table 3). TA content generally tended to regular increase during storage period in all samples as in Akan et al. (2019a). In the present study, increase in TA values was slowed down by MA packaging and the lowest average TA values were observed in LDPE-packed samples (0.37% citric acid). At the end of the storage period, the highest TA was in controls (0.70% citric acid) and this was followed by CPTB (0.54% citric acid) and LDPE- packed (0.42% citric acid) samples. As it can be followed in Table 3, controls had higher SSC and TA values at the end of the storage period and this could be resulted from higher weight loss in these samples. On the other hand, some researches has reported

Table 3: Effect of different package materials on soluble solids content (SSC), titratable acidity (TA), total phenolic content (TPC) and antioxidant capacity (AOC) of green garlic leaves during a storage period of 12 days under 10°C, 75-85% RH conditions

Factors	SSC *(%)*	TA *(% citric acid)*	TPC (mg GAE $g^{-1}FW^{-1}$)	AOC (I%)
Storage period (SP) (days)				
0	16.10±0.00[1]	0.30±0.005	0.07±0.0022	56.37±0.03
3	16.83±0.79^{A}[2]	0.37±0.014^{C}	0.07±0.0005^{B}	51.47±3.92^{B}
6	13.80±0.37^{C}	0.38±0.011^{C}	0.08±0.0016^{A}	39.05±4.86^{C}
9	15.26±0.38^{B}	0.46±0.033^{B}	0.07±0.0023^{B}	43.44±4.21^{BC}
12	14.76±0.39^{BC}	0.56±0.040^{A}	0.07±0.0023^{B}	65.45±2.56^{A}
Package materials				
Control (-MAP)	16.32±0.63^{A}	0.52±0.037^{A}	0.07±0.0017^{B}	49.38±3.21^{ns}
CPTB	14.98±0.42^{B}	0.43±0.022^{B}	0.08±0.0013^{A}	54.20±5.25^{ns}
LDPE	14.19±0.34^{B}	0.37±0.012^{C}	0.07±0.0011^{B}	45.98±4.66^{ns}
SP × PM				
3rd day×control	19.73±0.03^{A,a}[3]	0.41±0.011^{C,a}	0.07±0.0001^{A,a}	40.88±2.40^{ns}[4]
3rd day×CPTB	15.00±0.95^{AB,b}	0.38±0.024^{C,a}	0.07±0.0008^{B,a}	62.48±2.56^{ns}
3rdday×LDPE	15.77±0.43^{A,b}	0.33±0.006^{C,b}	0.07±0.0001^{B,a}	51.05±7.41^{ns}
6th day×control	14.00±0.05^{C,a}	0.41±0.001^{C,a}	0.07±0.0003^{A,b}	39.88±5.01^{ns}
6th day×CPTB	13.70±1.25^{B,a}	0.36±0.020^{C,b}	0.08±0.0020^{A,a}	38.97±13.10^{ns}
6th day×LDPE	13.70±0.35^{B,a}	0.37±0.024^{B,ab}	0.08±0.0012^{A,a}	38.28±9.24^{ns}
9th day×control	16.07±0.03^{B,a}	0.58±0.002^{B,a}	0.07±0.0046^{A,b}	54.05±0.56^{ns}
9th day×CPTB	15.60±0.51^{A,ab}	0.43±0.004^{B,b}	0.08±0.0015^{A,a}	43.70±8.00^{ns}
9th day×LDPE	14.10±0.70^{B,b}	0.36±0.011^{B,c}	0.07±0.0010^{B,b}	32.57±5.70^{ns}
12th day×control	15.47±0.06^{BC,a}	0.70±0.006^{A,a}	0.06±0.0006^{B,b}	62.70±0.55^{ns}
12th day×CPTB	15.60±0.00^{A,a}	0.54±0.013^{A,b}	0.07±0.0011^{B,a}	71.65±2.52^{ns}
12th day×LDPE	13.20±0.05^{B,b}	0.42±0.016^{A,c}	0.07±0.0002^{B,a}	62.01±6.58^{ns}
Significant effects				
SP	0.000[5]	0.000	0.000	0.000
PM	0.000	0.000	0.000	0.213
SP×PM	0.001	0.000	0.014	0.202

[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]Capital letters show differences among storage periods for each packaging material, lower letters show differences between the packaging materials for each storage period ($P \leq 0.05$). [4]ns: no significant. [5]P values calculated by variance analysis.

that higher TA was caused from microbial activity. A report by Soccol et al. (2006) who indicated that *Penicillium* spp. increased the acidity of stored foods in parallel with increased microbial activity. Other report indicated that the increase of acidity can also be due to texture and cell damage during the cutting process (Memon et al., 2018). Additionally, the decrease of SSC may be resulted from the breakdown of sugars depending on respiration process (Özden and Bayindirli, 2002; Torun, 2015; Akan et al., 2019b). In the current study, it was found that SSC and TA values are better maintained in CPTB material than LDPE.

Total phenolic content (TPC) of garlic leaves changed based on SP × PM interactions (P = 0.014) (Table 3). During whole storage period, average TPC values showed an increase up to 6th day and then decrease until the end of storage period. CPTB-packed samples had higher average TPC than controls and LDPE-packed samples. At the end of the storage period, both packaging materials helped keeping TPC in green garlic leaves (Table 3). Sakaldas et al. (2010) also reported that MAP prevented the degradation of phenolic compounds in dill leaves.

Total antioxidant capacity in plants commonly includes phenolics, flavonoids, carotenoids, vitamins and sulfur compounds. To determine free radical scavenging activity, DPPH radical is used extensively (Baba and Malik, 2015). In our study, only storage period (SP) significantly affected TAC of garlic leaves (P = 0.000) (Table 3). In other words, MA packaging did not affect the keeping TAC levels of leaves. TAC decreased till the 9th day and then increased till the end of storage. During storage period, the garlic leaves stored at 12th day had highest (65.45 I%) and 6th day had lowest value (39.05 I%) (Table 3). Our results are consistent with a report by Koca et al. (2016), who stated that TAC values of fresh garlic ranged from 30.80 to 82.97%. In general, differences in TAC results are due to genetic resources, ecological factors and storage conditions (Bayili, 2011). Issa et al. (2013) determined that TAC in green onion leaves as 83% and indicated that free radicals generated during storage may act as stress signals and may trigger some stress responses, resulting in higher TAC content. In addition, Kevers et al. (2007) reported that the TAC decreased by 50% in leek at 4 °C temperature for 23 days, but continuously increased in onion bulb at room temperature. This statement partially in agreement with our

Table 4: Relationships among assessments investigated in green garlic leaves stored at 10°C, 75-85% RH conditions

Assessments	WL	SSC	TA	VQ	SPAD	L*	a*	b*	ΔE*	AOC
SSC	0.230^{1ns2}									
TA	0.801^{***3}	0.181^{ns}								
VQ	-0.482**	0.028^{ns}	-0.766***							
SPAD	-0.478**	0.295^{ns}	-0.168^{ns}	-0.541^{ns}						
L*	0.748***	0.105^{ns}	0.827***	-0.737***	-0.247^{ns}					
a*	-0.603***	-0.002^{ns}	-0.734***	0.818***	0.242^{ns}	-0.885***				
b*	0.689***	0.015^{ns}	0.794***	-0.809***	-0.273^{ns}	0.955***	-0.960***			
ΔE*	0.415^{ns}	0.218^{ns}	0.298^{ns}	-0.255^{ns}	-0.102^{ns}	0.552***	-0.603***	0.578***		
AOC	0.160^{ns}	-0.021^{ns}	0.474**	-0.434^{ns}	0.221^{ns}	0.325^{ns}	-0.273^{ns}	0.340*	0.055^{ns}	
TPC	-0.686***	-0.304^{ns}	-0.541***	0.361*	0.107^{ns}	-0.379*	0.208^{ns}	-0.335*	-0.156^{ns}	-0.290^{ns}

[1] Pearson correlation quotient, r^2, -1, +1, [2]ns; non-significant at P ≤ 0.05 error level. [3]* P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001

findings. On the other hand, our results are in agreement with Akan et al. (2019a; 2019c).

It was figured out that WL was positive correlated with TA (r^2 = 0. 801), L* (r^2 = 0. 748), and b* (r^2 = 0.689) but negatively correlated with VQ (r^2 = − 0. 482), SPAD (r^2 = −0. 478), a* (r^2 = −0. 603) and TPC (r^2 = −0. 686) (Table 4). VQ was positively correlated with a* and TPC (r^2 = 0.818 and r^2 = 0.361, respectively) and negatively correlated with L*, b* and TA (r^2 = −0. 818, r^2 = −0.809 and r^2 = −0. 766, respectively). Moreover, Pearson correlation tests showed that L* (r^2 = 0.827), b* (r^2 = 0.794) and TAC (r^2 = 0.474) parameters were positively correlated with TA. In addition, L* values strongly correlated with ΔE* and b* (r^2 = 0.552 and 0.955, respectively) and negatively correlated with a*, TPC and VQ (r^2 = −0.885, −0.379 and −0.737, respectively). Furthermore, a* was negatively correlated with TA and b* (r^2 = −0.734 and −0.960, respectively), b* was positively correlated with ΔE* and TAC (r^2 = 0.578 and r^2 = 0.340) and negatively correlated with TPC (r^2 = −0.335). TPC was only negatively correlated with TA (r^2 = −0.541) (Table 4). It can be concluded from this study that WL and color (L*, b*), TA, TAC could be used as marker to determine shelf life of green garlic leaves.

CONCLUSION

According to our results, both MAP materials used in this research reduced WL and slowed down decrease in SPAD values, VQ and TPC, significant changes in color parameters (L*, a*, b*, ΔE*) in green garlic leaves. However, clear differences between these two materials were not observed about keeping quality of leaves, but they manage quality better than controls. Without MAP, controls could be stored up to 3 days under 10 °C, 80±5% RH conditions, while packaging materials extended storage period till 12 days by considering WL values. As mentioned above, since green garlic is a high perishable crop and requires very special attention during postharvest period, it is a promising export crop for Turkey. Further studies have needed on different MAP materials in order to find the most suitable one based on green garlic's physiology and effects of them on senescence physiology.

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Authors' contributions

Selen Akan designed the study, performed experiments and analyzed data, wrote the whole paper; Özge Horzum co-designed the study, participated in performed experiments and data analysis. All authors read and approved the final manuscript.

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