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RESEARCH ARTICLE

Differential response of softneck and hardneck garlic ecotypes to quality attributes for long-term storage

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ABSTRACT

The selection of suitable garlic ecotypes is necessary for better storage quality to meet domestic and export requirements. For this purpose, ten promising garlic ecotypes, including hardneck and softneck types (Kilis, Mersin, Kahramanmaraş, Araban, Yavuzeli, Taşköprü, Nevşehir, Ankara, Aksaray, and Tokat) were examined to identify superior ecotype/s in terms of storability without detrimental changes for 6 months in warehouse condition. Thus, weight loss, sprouting ratio, and titratable acidity increased, whereas pH and antioxidant capacity decreased in all ecotypes with an increase in storage period. In addition, dissimilar behaviors were detected in SSC, ash, total phenolic, and macro- and micro minerals among ecotypes in relation to the storage period. This study demonstrates that Taşköprü, Tokat, Nevşehir, and Ankara ecotypes presented the best behaviors during storage, which are considered quality attributes and good indicators of predicting storage life. It also highlighted the potential of ecotype selection to prevent unacceptable levels of quality in garlic and the ecotype-dependent effect of long-term storage on quality parameters. Conclusively, it is possible to declare that softneck garlic ecotypes are more durable in the same storage conditions, considering the maintenance of quality attributes and good adaptation to longer storage. Therefore, the intensity of change in quality attributes was found to be crucial for identifying and choosing ecotypes to enhance the storage stability. It also imparts desirable properties for consumer acceptance and various processed garlic-based products.

Keywords: Antioxidant capacity; *Allium sativum* L.; Macro and microelements; Sprouting ratio; Total phenolics

INTRODUCTION

Garlic (*Allium sativum* L.) is in high demand due to its marketing value to both wholesalers and retailers. In Turkey, it is easily available on the market during the whole year, both as raw and processed products. No doubt, garlic has the ideal balanced flavor and nutritional value as a raw ingredient when incorporated into food products (Sharma et al., 2021). Garlic is an excellent dietary source of bioactive compounds, particularly organo- sulfide compounds (Beato et al., 2011) and phenolic compounds. These pronounced chemical compositions also change depending on the genotype (Akan, 2019; Petropoulos et al., 2018).

Despite the advancement of production technology, postharvest losses still pose a great problem. Garlic production is hampered by various storage losses, and this shows that garlic producers have not been able to meet the demand for food consumption in many countries. Garlic's reckless post-production practices, including harvesting, curing, storage, and handling cause severe quality losses. Therefore, proper storage is unavoidable across the augmenting market demand. Sharma et al. (2021) reported that storage losses of garlic were at 35-40% and major losses of garlic comprised weight loss and disease development. In addition, "waxy breakdown" is a main physiological disorder of garlic, it induces yellowish discoloration and a transparent appearance of cloves. Furthermore, it is caused by high temperatures during storage and leads to accelerated senescence (Ryall and Lipton, 1979). As a matter of fact, storage is the most important factor in garlic for supplying continuous desirable quality in accordance with market demand (Nurmalia et al., 2019). The main storage factors for garlic are storage temperature, relative humidity (RH), period, and modified or controlled atmospheric conditions (Madhu et al., 2019). In that sense, well-cured and cleaned garlic bulbs can be stored at -1 to 0°C with 60-70% RH for up to 12 months (Hannan and Sorensen, 2002). It is also reported that the storage life of garlic bulbs are 1-2 months at 20–30°C (Cantwell, 2004). When garlic bulbs are stored between 4 and 18°C, sprouting is observed rapidly, which

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eventually leads to high-quality losses (Desta et al., 2021). In addition, low RH (no more than 65-70%) is crucial for proper garlic storage management, because high RH (above 70%) favors weight loss, decay, and root growth (Akan and Tuna Gunes, 2021; Vazquez-Barrios et al., 2006). It has been suggested that for the best storage of garlic bulbs against pests, pathogens, and the fungi, the temperature and RH should be between 13 and 18°C, and 40 and 60% respectively, because they are less active at this condition (Madhu et al., 2019).

Growing, obtaining high yields, and storability for long-term garlic is directly dependent on variety (Akan, 2019; Volk et al., 2004). Garlic varieties have been divided into 2 main types: softneck (*Allium sativum var. sativum*) and hardneck (*Allium sativum var. ophioscorodon*). Softneck garlic varieties can be stored for longer and have a better storage ability than hardneck varieties (Block, 2010). For instance, softneck garlic varieties can be stored under commercial storage conditions for up to 9 months when stored at 0°C or for 1 to 2 months at 20°-30°C. On the other hand, hardneck varieties can be stored for up to 6 months under ideal conditions (Harris, 2016). According to the TurkStat data, in Turkey, softneck garlic varieties have commonly used in commercial mass production until last year (TurkStat, 2021). However, nowadays, hardneck garlic preference has replaced softneck. The selection of garlic types can vary tremendously from one location to another, considering erratic climatic conditions (Raslan et al., 2015). Domestic ecotypes are completely adapted to the local conditions that are recommended for their usage and storage. It is pivotal in ensuring long-term storage without significant deterioration for acceptable quality as well as obtaining a high yield. In Turkey, garlic is harvested from the beginning of May to the end of July and then stored to ensure a year-round supply. Although garlic is stored commercially in warehouses for up to 9 months, it is not obvious whether this storage regime is ideal or not for the preservation of biochemical quality over the course of time. The current storage methods focused on ensuring healthy bulbs such as being free from sprouting, disease and injury, but biochemical quality control is not routinely performed during storage (Ludlow et al., 2021). The selection of garlic varieties and available storage options do not make matters any easier to meet market standards throughout the year. To the best of our knowledge, there is a gap in previous studies on clarifying the behavior of different garlic ecotypes under the same storage conditions. Innumerable studies on improving the storage life of softneck and hardneck garlic cultivars have been performed separately. However, up to date, information on the comparative response to the biochemical and physical quality of the softneck and hardneck garlic ecotypes during long-term storage has been lacking. It is required to monitor the storage life of these different ecotypes during storage as well as their physical attributes. Therefore, good and protective storage methods will be enhanced in the future based on specific physiological responses recorded in this study. Hence, this study aimed to evaluate the similarities and differences between softneck and hardneck garlic ecotypes in terms of storage performance under uncontrolled commercial conditions in warehouses for 6 months. Another significant aim of this study is the identification of superior ecotypes in garlic varieties according to their extended postharvest quality retention to overcome a considerable gap in continuous supply to domestic and overseas markets. Therefore, promising high-quality ecotypes will make garlic a commodity of international prominence.

MATERIALS AND METHODS

Plant material

Garlic bulbs of each ecotype were collected from farmers in the most important regions for garlic cultivation after harvesting and curing naturally by observing maturity indices in 2020. Considering that, 10 garlic ecotypes from sampling regions extend all over Turkey. There is a huge diversity in planting and harvesting times among the selected ecotypes. Further details about each ecotype are presented in Table 1. Following the collection, experimentally high-quality bulbs were chosen including those free from sprouting damage, uniformity and exhibiting size.

Storage conditions

All garlic ecotypes were stored in the experimental warehouse in dark conditions for 6 months. During the storage period, the cooling of the room was enabled ventilation throughout the night by opening doors. As depicted in Fig. 1, the temperature and relative humidity (RH) of the warehouse were recorded using a thermo-hygrometer (Wewell, VHM 140). During the storage period, average storage temperatures and RH were recorded in a warehouse at 13 °C and 62% (Fig. 1).

Quality attributes

The garlic bulbs were randomly selected from the crates to record observations on various quality attributes. These attributes were evaluated at bimonthly intervals (0, 2, 4, and 6) during a storage period of 6 months.

Weight loss (WL)

WL was determined using a digital scale (±0.01 g) (Mettler Toledo, Ohio, USA) and following the method by Sharma et al. (2020) during storage and as given below:

$$(\mathrm{WL})(\%) = \frac{\text{Initial weight of bulbs} - \text{weight of bulbs at particular time interval}}{\text{Initial weight of the bulbs}} \times 100$$

Table 1: Description of the studied ecotypes concerning region, type of cultivation, planting-harvesting time, and garlic type

Ecotype name	Region/Collected district	Type of cultivation	Planting time	Harvesting time	Type
Kilis	Kilis/Centre	Local landrace	October	June	Hardneck
Mersin	Mersin/Erdemli	Local landrace	September	June	
Kahramanmaraş	Kahramanmaraş/Pazarcık	Commercially cultivated	September	May	
Araban	Gaziantep/Araban	Commercially cultivated	October	May	
Yavuzeli	Gaziantep/Yavuzeli	Local landrace	October	May	
Taşköprü	Kastamonu/Taşköprü	Commercially cultivated	February	July	Softneck
Nevşehir	Nevşehir/Centre	Local landrace	October	June	
Ankara	Ankara/Afşar	Local landrace	November	June	
Aksaray	Aksaray/Acıpınar	Commercially cultivated	October	June	
Tokat	Tokat/Kızılca	Commercially cultivated	February	July	

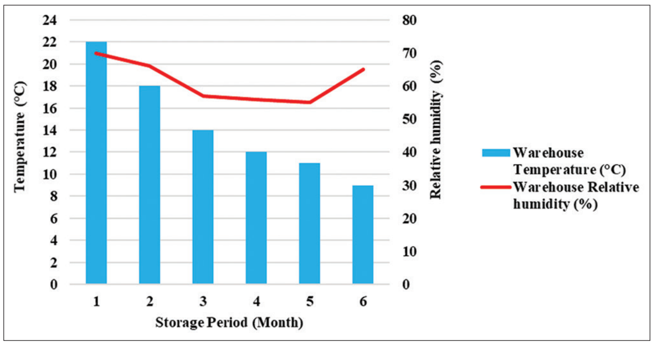

Fig 1. Monthly average temperature and relative humidity values of stored warehouse

Sprouting ratio (ST), rooting score (RS) and waxy breakdown (WB)

SR was determined using the following formula (Sharma et al., 2020):

$$\text{Sprouting percentage} = \frac{\text{Number of sprouted clovesper bulb}}{\text{Total number of clovesper bulb}} \times 100$$

A rooting score of cloves was evaluated visually and presented as the percentage of garlic clove number showing corresponding symptom in the whole group (Kang and Lee, 1999). The occurrence of waxy breakdown was counted based on the number of waxy breakdown in each bulb (Nurmalia et al., 2019).

Soluble solids content (SSC) and ash content

SSC was determined by a digital abbe refractometer (Leica 10480, Germany) and presented as a percentage (%). The ash content of garlic was determined according to AOAC (2000) and given as a percentage (%).

Titratable acidity (TA) and pH

TA was measured by an automatic titrator (DL 50 Mettler) and the results were expressed as citric acid %. The pH value was recorded with a digital pH meter MP 220 (Mettler Toledo).

Antioxidant capacity (AOC) and total phenolic content (TPC)

The extraction of antioxidant capacity and total phenolic content measurement were carried out according to Brand-Williams et al. (1995) and Zor (2006) methods with some modifications. Briefly, a 5 g sample was homogenized with 25 mL of distilled water by a homogenizer (IKA-Labortechnik, Ultra-turrax T25) for 20 sec. The homogenate was kept in dark room conditions for 30 min. After centrifuging, 10,000 × g at 4 °C for 10 min, the supernatant was transferred to a centrifuge tube and this step (centrifugation of the supernatant) was repeated twice. Then, combined supernatants were used for determinations.

The AOC analysis was evaluated by the radical scavenging activity of the 2,2-diphenyl-1-picrylhydrazyl (DPPH) according to Brand-Williams et al. (1995) with a spectrophotometer (Shimadzu UV/VIS). The AOC results were expressed as a percentage of inhibition (I%) according to the formula:

$$\text{Inhibition } \% = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

The TPC was determined with the Folin-Ciocalteu reagent described by Lu et al. (2011). The absorbance was measured at 765 nm on a UV/Vis spectrophotometer (Shimadzu, Kyoto, Japan). The TPC results were expressed as mg of gallic acid equivalents per gram in fresh (mg GAE g^{-1} fw).

Macro-and micro mineral contents

The macro-and micro mineral analysis was performed based on a procedure previously described by Petropoulos et al. (2018). Garlic samples were dried at 72 °C in a forced-air oven until they reached a constant weight. The dried samples were then ground into a powder using a grinder and extracted with 1 N HCl to obtain the final solution.

Atomic absorption spectrophotometry (Perkin Elmer 1100B, Waltham, MA, USA) was used to determine calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) contents. Thereafter, flame photometry (Sherwood Model 410, Cambridge, UK) was used to determine sodium (Na) and potassium (K) contents.

Statistical analysis

All measurements were performed in triplicate, each replication included ten bulbs, and analysis was carried out on thirty randomly selected cloves. The experimental design was a completely randomized design (CRD) in which ecotypes and storage period were considered as the main factors. Experimental data were analyzed by ANOVA in MINITAB Software (Trial Version, United Kingdom) and Tukey's honestly significant difference test (MSTAT-C software) was used for multiple comparisons among genotypes, storage period, and their interactions at a significance level of $P \leq 0.05$. Additionally, hierarchical clustering analysis (HCA) was carried out to assess variation and relationships among ecotypes by employing JMP software (version 16, SAS Inc., Cary, NC, USA). The results were also presented both in constellation plots showing group/cluster relationships as well as in dendrograms.

RESULTS AND DISCUSSION

Weight loss (WL)

The WL of the garlic ecotypes is presented in Table 2. In all ecotypes, the trend of percent WL increased with the advancement of the storage period, in agreement with previous research (Ludlow, 2019). Significant differences ($P \leq 0.05$) were determined among garlic ecotypes. At the end of the storage period, it was discovered that the Yavuzeli ecotype had the highest WL value (55%), while the Tokat ecotype had the lowest WL value (11.42%), indicating high- and low-quality deterioration. Apart from the Tokat ecotype, low WL values appeared in the Ankara (12.50%) whereas the Kahramanmaraş showed the second highest values (30.56%) in the 6^{th} month of storage. Our results (2.53 and 11.49%) were lower than the values reported by Kowser et al. (2018), who found WL between 5.45 and 53.01% in different garlic genotypes after two months of storage. This may be owing to the dissimilar behaviors of the varieties studied by these authors. To back this up, the respiration rate of garlic ecotypes increased (data not shown) during storage, which indicates an increase in physiological activity that contributes to greater WL as mentioned in Nurmalia et al. (2019) and Vazquez-Barrios et al. (2006). The WL value may therefore be considered as an effective limit for maintaining garlic. One of the factors that could be used to estimate storage life is WL. In Turkey, it has already been pointed out that a WL of up to 15% could be an acceptable rate for garlic, and this would permit marketing of the product (TOBB, 2022). Considering the acceptable rate, the storability of ecotypes Kilis and Yavuzeli for 2 months; Mersin, Kahramanmaraş and Araban for 4 months; Taşköprü, Nevşehir, Ankara, Aksaray, and Tokat for 6 months.

Sprouting ratio (SR), rooting score (RS) and waxy breakdown (WB)

As summarized in Table 2, the SR values ranged between 0-100% during the whole experimental period. As the storage period prolonged, the SR increased except for the Taşköprü and Tokat ecotypes. After 2 months of storage, the SR began to increase in some ecotypes, although this tendency was most pronounced in the ecotypes including Araban (64.04%), Kahramanmaraş (58.34%), and Yavuzeli (43.73%), which showed that the dormancy period was short in these ecotypes. The results of the SR are in partial agreement with those reported by Cantwell and Mann (2004) and Lewis (1956) who describe an early onset of sprouting at intermediate temperatures. On the other hand, there were no appreciable changes in this parameter up to 6 months of storage in Taşköprü and Tokat ecotypes, which implies that the garlic was still dormant. However, ecotypes such as Mersin, Araban, Ankara, and Aksaray have reached a maximum occurrence (100%) at the end of storage. The results mentioned above suggest that the SR of each ecotype gave different responses to the storage period, which is in line with a report by Nurmalia et al. (2019) indicating that the dormancy period varies depending on the variation in genotypes. Wheeler et al. (1998) also revealed that sprouting in storage was related to lower levels of total water-soluble solids in the bulbs, which was mostly related to the early harvest. The shelf life of ecotypes would be determined by the dormancy period, and this parameter could be used as an indicator. However, for a SR to be a more precise indicator, parallel changes in other quality attributes are required. Vazquez-Barrios et al. (2006) propose the SR of 50% as a shelf life limit. Based on this previous data, the storage period could be advised as 2 months for the ecotypes Mersin, Kahramanmaraş, Araban and Yavuzeli; 4 months for Kilis, Ankara and Aksaray; 6 months for Taşköprü, Tokat and Nevşehir.

Regarding RS, the results remained unchanged in all tested ecotypes during storage at each analysis time. Namely, we did not observe the rooting in all ecotypes over the course of storage thus; we could not record the RS values. Concerning waxy breakdown, there was no detectable WB in any sample throughout the experiment. This shows that each ecotype gives the same responses in terms of WB

Table 2: Weight loss (WL), sprouting ratio (SR), soluble solids (SSC) and ash content of garlic ecotypes during storage at warehouse conditions for 6 months

Factors	WL (%)	SR (%)	SSC (%)	Ash (%)
Ecotype (E) × Storage Period (SP)				
Kilis × 0th month	0.00±0.00D,a*	0.00±0.00C,a	23.73±0.26D,e	1.24±0.02C,h
Kilis × 2nd month	11.49±0.09C,a	0.00±0.00C,e	28.07±1.01C,d	1.25±0.01C,bc
Kilis × 4th month	19.40±0.09B,b	25.89±0.04B,g	31.03±0.03B,a	1.44±0.03B,d
Kilis × 6th month	28.47±0.09A,c	59.39±0.01A,d	40.53±0.08A,a	1.52±0.00A,b
Mersin × 0th month	0.00±0.00D,a	0.00±0.00D,a	35.03±0.12A,c	3.70±0.04A,a
Mersin × 2nd month	3.89±0.02C,def	20.30±0.35C,d	30.70±0.15B,c	0.55±0.03D,f
Mersin × 4th month	10.58±0.05B,e	66.64±0.39B,c	25.03±0.03C,b	1.56±0.00B,c
Mersin × 6th month	18.30±0.08A,e	100.00±0.00A,a	35.13±0.03A,ef	1.45±0.01C,c
Kahramanmaraş × 0th month	0.00±0.00D,a	0.00±0.00D,a	34.90±0.10A,c	1.98±0.00A,d
Kahramanmaraş × 2nd month	6.41±0.15C,c	58.34±0.02C,b	32.43±0.06B,bc	1.25±0.00B,bc
Kahramanmaraş × 4th month	16.85±0.02B,c	83.32±0.01B,a	30.73±0.03B,a	0.97±0.00C,ef
Kahramanmaraş × 6th month	30.56±0.16A,b	90.89±0.00A,b	36.06±0.03A,cde	1.22±0.00B,f
Araban × 0th month	0.00±0.00D,a	0.00±0.00D,a	38.50±0.11A,b	1.55±0.00C,ef
Araban × 2nd month	4.30±0.03C,d	64.04±0.38C,a	36.83±0.08A,a	1.76±0.00B,a
Araban × 4th month	13.36±0.23B,d	78.22±0.22B,b	23.46±0.11C,bc	1.81±0.00A,a
Araban × 6th month	26.22±0.06A,d	100.00±0.00A,a	33.03±0.03B,f	1.26±0.00D,ef
Yavuzeli × 0th month	0.00±0.00D,a	0.00±0.00D,a	35.16±0.08B,c	1.56±0.00B,e
Yavuzeli × 2nd month	9.01±0.02C,b	43.73±0.03C,c	28.40±0.11C,d	1.29±0.00C,b
Yavuzeli × 4th month	22.01±1.49B,a	62.55±0.02B,d	21.86±0.03D,cd	1.71±0.00A,b
Yavuzeli × 6th month	55.09±0.20A,a	71.22±0.03A,c	37.63±0.08A,bcd	1.68±0.00A,a
Taşköprü × 0th month	0.00±0.00D,a	0.00±0.00A,a	38.46±0.03A,b	2.76±0.00A,c
Taşköprü × 2nd month	3.19±0.09C,efg	0.00±0.00A,e	37.43±0.08A,a	0.98±0.00B,e
Taşköprü × 4th month	6.56±0.00B,g	0.00±0.00A,i	23.56±0.03B,bc	0.99±0.00B,ef
Taşköprü × 6th month	12.45±0.11A,gh	0.00±0.00A,f	37.76±0.06A,bcd	1.01±0.00B,g
Nevşehir × 0th month	0.00±0.00D,a	0.00±0.00C,a	43.90±0.25A,a	1.46±0.00A,g
Nevşehir × 2nd month	4.35±0.06C,d	0.00±0.00C,e	31.63±0.08C,bc	1.24±0.00C,bc
Nevşehir × 4th month	6.72±0.06B,g	23.07±0.01B,h	31.13±0.06C,a	1.02±0.01D,e
Nevşehir × 6th month	12.19±0.14A,gh	41.63±0.04A,e	39.60±0.05B,ab	1.29±0.00B,e
Ankara × 0th month	0.00±0.00D,a	0.00±0.00C,a	38.86±0.06A,b	1.46±0.00A,g
Ankara × 2nd month	2.86±0.06C,fg	0.00±0.00C,e	36.80±0.11B,a	1.22±0.00C,c
Ankara × 4th month	6.34±0.07B,g	27.00±0.00B,f	31.46±0.03C,a	0.94±0.02D,f
Ankara × 6th month	12.50±0.10A,g	100.00±0.00A,a	37.53±0.03AB,bcd	1.37±0.02B,d
Aksaray × 0th month	0.00±0.00D,a	0.00±0.00C,a	32.53±0.03B,d	1.50±0.00A,fg
Aksaray × 2nd month	2.53±0.03C,g	0.00±0.00C,e	30.26±0.23C,cd	1.01±0.00C,e
Aksaray × 4th month	8.11±0.05B,f	28.55±0.03B,e	20.80±0.00D,d	1.47±0.01A,d
Aksaray × 6th month	15.83±0.03A,f	100.00±0.00A,a	35.66±0.03A,de	1.22±0.00B,f
Tokat × 0th month	0.00±0.00D,a	0.00±0.00A,a	42.43±0.03A,a	3.02±0.01A,b
Tokat × 2nd month	4.14±0.04C,de	0.00±0.00A,e	33.30±0.05C,b	1.15±0.00B,d
Tokat × 4th month	7.16±0.04B,fg	0.00±0.00A,i	29.76±0.03D,a	0.75±0.00D,g
Tokat × 6th month	11.42±0.06A,h	0.00±0.00A,f	38.06±0.03B,bc	1.00±0.00C,g
Significant effects				
E	0.000	0.000	0.000	0.000
SP	0.000	0.000	0.000	0.000
E×SP	0.000	0.000	0.000	0.000

*mean±standard error of mean (SEM). Capital letters show differences among storage periods in each ecotype, lower letters show differences between ecotypes in each storage period at $P \leq 0.05$ error level according to Tukey's test

during storage. Nurmalia et al. (2018) reported a similar behavior for WB in garlic bulbs during 4 months of storage. On the other hand, Kowser et al. (2018) noted significant increase in WB of garlic during 4 months of storage. Our samples that are free of WB could be resulted from not being subjected to a high temperature before harvest, which explained in a report by Schwartz (1995).

Soluble solids content (SSC) and ash content

Genotypes that have higher SSC content could be utilized for the processing purposes (Singh et al., 2011). In Table 2, the experiments demonstrated that there were some fluctuations in the values of SSC in garlic ecotypes throughout the storage, which is in line with the results of Kopsell and Randle (1997) in onion. According to the current findings, the initial values of SSC varied between 23.73 and 43.90% among different ecotypes, and all ecotypes decreased from the 0th to 4th month, and then increased in the 6th month of storage except for the Kilis ecotype. The highest values were noticed in ecotype Kilis (40.53%), while ecotype Araban (33.03%) had the lowest values at the end of the storage. When considering each ecotype's behavior during the storage period, the highest increases from the beginning to the end of storage were in ecotype Kilis (23.73 to 40.53%), and the highest decrease was in ecotype Araban (38.50 to 33.03%). The reason for the proportional rise in SSC of garlic could be a result of an increment in weight loss. This situation was also reported by Akan et al. (2019), as well as Akan and Tuna Gunes (2021) in garlic during storage.

The ash content of garlic ecotypes was found to range from the initial range of 1.24-3.70% to the final range of 1.00-1.68% during the storage period of six months (Table 2). Except for ecotypes Kilis and Yavuzeli, the ash content diminished and increased at different rates in other ecotypes at the end of storage. While the highest reduction in ash content was determined in Mersin and Tokat ecotypes, the highest increment was in Mersin and Yavuzeli ecotypes. There has been very limited information in the literature regarding the ash content of garlic bulbs and its changes during storage. According to experience, the previously mentioned discrepancies in the results may be related to the variations in cultivation conditions, harvesting and curing time. The results of ash content are in partial agreement with those reported by Bahnasawy and Dabee (2006) who noticed that ash content increased from 1.61 and 1.65% for the garlic stored traditionally. Petropoulos et al. (2016) have also reported an increase in the ash content of onions after long-term storage.

Titratable acidity (TA) and pH

As seen in Table 3, the TA value increased as the storage period increased and compared to initial values (0.180-0.411%), garlic ecotypes were more acidic after 6 months of storage (0.537-0.965%). During the whole experiment, Kilis ecotype had the highest and Nevşehir ecotype had the lowest increase in TA, which ranged from 0.180 to 0.823% and from 0.246 to 0.537%, respectively. Akan et al. (2019), Akan and Tuna Gunes (2021), Dronachari et al. (2010) similarly observed an increase in the ratio of TA in garlic cloves and bulbs during storage. A reverse trend was observed in pH values of all ecotypes with the progress of the storage period and this pattern of change was in line with TA results. The initial pH values of garlic ecotypes varied between 6.77 and 7.01, pH increased in most garlic ecotypes in the 6th month. Compared to initials, pH values decreased to the range of 6.11-5.98 within samples after 6 months (Table 3). The decline in pH of Aksaray ecotype occurred at a faster rate than in others, whereas the slowest decline was determined in ecotype Ankara at the end of the storage.

As mentioned earlier, a gradual increase in the percentage of acidity occurred, but the pH decreased during storage (Table 3). Berno et al. (2014) described similar changes in onions during storage. Because the TA and pH are associated with the organic acid content, high stress due to microbial activity in stored foods is one of the obvious consequences of a larger production of these acids leading to an increase in acidity and a reduction in pH values (Soccol et al., 2006).

Antioxidant capacity (AOC) and total phenolic content (TPC)

The AOC content of the ecotypes differed significantly both at the initial and at the end of storage (Table 3). The AOC in garlic for all ecotypes appears lower in stored ecotypes than prior to storage. Similarly, Akan and Tuna Gunes (2021) observed a decrease in the AOC of garlic bulbs stored for 6 months. Previous reports have shown that storing garlic cloves for a longer period of time can help decrease AOC levels (Veríssimo et al., 2010; Li et al., 2015; Akan et al., 2019). The reduction in AOC of garlic ecotypes after storage for 6 months was the lowest in Mersin (~7%) and Aksaray (~16%) whereas it was the highest in Kilis (~31%) and Yavuzeli (~24%). On the other hand, during the whole experiment, Taşköprü, Nevşehir, and Ankara ecotypes had a relatively high content of AOC, respectively. This discrepancy amongst obtained results of the AOC level of ecotypes could be attributed to different ecotypes being cultivated in different areas. Besides, there are differences in cultivation practices and microclimate conditions between these areas. Denre et al. (2013) and Petropoulos et al. (2018) also observed a significant variation in AOC among diverse garlic cultivars and they have reported similar results.

As for TPC, there was a considerable change in values between ecotypes (Table 3). Our results are compatible with some reports, which found a significant variation in TPC results of garlic (Hirata et al., 2015; Petropoulos et al., 2018). The disparities in the data obtained herein could be owing to genetic factors, climatic and growing conditions and so forth. Even, Beato et al. (2011) have revealed that the same garlic cultivars at four different locations show a significant effect of growing conditions on TPC. At the beginning of storage, the ecotypes Tokat and Kilis showed the highest and lowest TPC, respectively (34.88 and 24.67 mg GAE 100 g^{-1} fw), while the other ecotypes showed intermediate values. TPC either increased (Kilis, Mersin, Yavuzeli, Nevşehir, and Aksaray) or slightly decreased by 9% (Kahramanmaraş and Araban) at the end of the trial. The ecotypes Taşköprü, Ankara, and Tokat had returned to their initial value by the end of the experiment.

Table 3: Titratable acidity (TA), pH, antioxidant capacity (AOC), and total phenolic content (TPC) of garlic ecotypes during storage at warehouse conditions for 6 months

Factors	TA (citric acid %)	pH	AOC (%I)	TPC (mg GAE 100 g^{-1})
Ecotype(E)×StoragePeriod(SP)				
Kilis × 0th month	0.180±0.00D,f*	7.00±0.02A,a	62.33±0.66A,d	24.67±0.06D,g
Kilis × 2nd month	0.383±0.00C,d	6.46±0.00B,a	53.33±0.33B,d	34.30±0.04A,c
Kilis × 4th month	0.614±0.00B,c	5.82±0.00D,b	48.33±0.33C,d	31.24±0.04B,e
Kilis × 6th month	0.823±0.00A,d	6.10±0.00C,a	43.33±0.33D,e	28.18±0.03C,g
Mersin × 0th month	0.314±0.00D,d	6.88±0.00A,c	55.67±3.71B,e	28.89±0.03D,de
Mersin × 2nd month	0.419±0.00C,d	6.25±0.00B,de	61.00±0.57A,c	38.30±0.04A,b
Mersin × 4th month	0.578±0.01B,def	5.72±0.00D,d	55.00±0.57B,c	33.61±0.03B,cd
Mersin × 6th month	0.647±0.00A,f	5.98±0.00C,c	52.00±0.00C,cd	30.38±0.12C,ef
Kahramanmaraş × 0th month	0.389±0.00D,ab	6.77±0.01A,e	65.66±0.33A,c	30.27±0.03B,bcd
Kahramanmaraş × 2th month	0.564±0.00C,a	6.23±0.00B,e	61.33±0.33B,c	33.68±0.03A,c
Kahramanmaraş × 4th month	0.787±0.01B,a	5.65±0.00D,e	58.66±0.33C,b	30.86±0.04B,e
Kahramanmaraş × 6th month	0.965±0.00A,a	6.01±0.00C,bc	55.00±0.57D,c	27.56±0.03C,g
Araban × 0th month	0.411±0.01D,a	6.84±0.01A,cd	66.33±0.33A,c	31.49±0.01B,b
Araban × 2nd month	0.528±0.00C,b	6.35±0.01B,c	59.00±0.57B,c	35.44±0.01A,c
Araban × 4th month	0.603±0.00B,cd	5.79±0.01D,bc	55.33±0.33C,c	31.14±0.01B,e
Araban × 6th month	0.869±0.01A,bc	6.02±0.01C,bc	51.33±0.33D,d	28.70±0.00C,a
Yavuzeli × 0th month	0.407±0.00D,a	6.84±0.00A,cd	66.66±0.33A,c	31.38±0.01D,bc
Yavuzeli × 2nd month	0.518±0.00C,b	6.28±0.00B,d	58.33±0.33B,c	38.31±0.00A,b
Yavuzeli × 4th month	0.721±0.00B,b	5.75±0.00D,cd	54.00±0.57C,c	35.42±0.00B,bc
Yavuzeli × 6th month	0.898±0.00A,b	6.11±0.00C,a	50.66±0.33D,d	32.24±0.01C,cde
Taşköprü × 0th month	0.384±0.00D,ab	6.84±0.00A,cd	75.33±0.33A,a	33.86±0.02C,a
Taşköprü × 2nd month	0.526±0.00C,b	6.23±0.00B,e	70.66±0.33B,a	39.73±0.01A,b
Taşköprü × 4th month	0.567±0.00B,ef	5.71±0.00D,d	65.33±0.66C,a	36.12±0.01B,b
Taşköprü × 6th month	0.675±0.00A,ef	6.03±0.00C,b	62.33±0.33D,a	33.24±0.02C,bcd
Nevşehir × 0th month	0.246±0.00D,e	6.94±0.00A,b	72.33±0.33A,ab	25.86±0.03C,fg
Nevşehir × 2nd month	0.385±0.00C,d	6.41±0.00B,b	68.33±0.33B,ab	33.71±0.04A,c
Nevşehir × 4th month	0.420±0.00B,h	5.71±0.00D,d	64.66±0.33C,a	30.16±0.03B,e
Nevşehir × 6th month	0.537±0.00A,g	6.05±0.00C,b	61.33±0.33D,ab	33.65±0.07A,bc
Ankara × 0th month	0.344±0.00C,cd	6.81±0.00A,de	71.00±0.57A,b	27.67±0.02C,ef
Ankara × 2nd month	0.460±0.02B,c	6.40±0.00B,b	65.33±0.33B,b	35.09±0.02A,c
Ankara × 4th month	0.515±0.00A,g	5.88±0.00D,a	61.33±0.33C,b	31.81±0.04B,de
Ankara × 6th month	0.541±0.00A,g	6.11±0.00C,a	58.33±0.66D,b	28.82±0.09C,fg
Aksaray × 0th month	0.368±0.01C,bc	7.01±0.00A,a	48.33±0.33A,f	29.23±0.17C,cde
Aksaray × 2nd month	0.396±0.02C,d	6.40±0.00B,b	45.33±0.33B,e	34.85±0.04A,c
Aksaray × 4th month	0.554±0.00B,f	5.65±0.00D,e	42.00±0.57C,e	30.79±0.08BC,e
Aksaray × 6th month	0.856±0.00A,cd	6.10±0.00C,a	40.66±0.33C,e	31.11±3.37B,de
Tokat × 0th month	0.393±0.01D,ab	6.88±0.00A,c	65.66±0.33A,f	34.88±0.03C,a
Tokat × 2nd month	0.527±0.00C,b	6.22±0.00B,e	58.33±0.33B,c	42.20±0.02A,a
Tokat × 4th month	0.591±0.00B,cde	5.82±0.00D,b	54.66±0.33C,c	38.61±0.03B,a
Tokat × 6th month	0.686±0.00A,e	6.05±0.00C,b	50.66±0.33D,d	34.70±0.04C,b
Significanteffects				
E	0.000	0.000	0.000	0.000
SP	0.000	0.000	0.000	0.000
E×SP	0.000	0.000	0.000	0.000

*mean±standard error of mean (SEM). Capital letters show differences among storage periods in each ecotype, lower letters show differences between ecotypes in each storage period at P ≤ 0.05 error level according to Tukey's test

Herein, the rise of TPC values in some garlic ecotypes during storage is in agreement with previous reports (Veríssimo et al., 2010; Lu et al., 2011). Conversely, the descending tendency in TPC of some garlic ecotypes was consistent with a report by Akan and Tuna Gunes (2021) in garlic bulbs for long-term storage. The increase in TPC could likely be related to the defense strategy of vegetables against oxidative stress (Silva et al., 2010) whereas the decrease in TPC may also be associated with the decrease in antioxidant activity.

Macro-and micro mineral contents

The results of the macro and micro mineral content analyses of the garlic ecotypes were presented with respect

Table 4: Macro- and micro element contents of garlic ecotypes during storage at warehouse conditions for 6 months

Factors	K (mgL^{-1})	Ca (mgL^{-1})	Mg (mgL^{-1})	Fe (mgL^{-1})	Cu (mgL^{-1})	Mn (mgL^{-1})	Na (mgL^{-1})	Zn (mgL^{-1})
Ecotype(E)×StoragePeriod(SP)								
Kilis × 0th month	451.66±1.22B,a*	4.89±0.07B,def	22.59±0.01C,a	0.164±0.00C,h	0.038±0.00C,f	0.117±0.01C,ef	11.54±0.01A,a	0.374±0.00B,c
Kilis × 2nd month	475.10±1.14A,bcd	6.15±0.34A,ab	21.52±0.02D,d	0.745±0.00B,e	0.109±0.01B,b	0.209±0.00B,bc	10.69±0.10B,c	0.374±0.00B,c
Kilis × 4th month	455.49±1.26B,bc	4.94±0.07B,de	23.74±0.00B,a	0.166±0.00C,h	0.040±0.00C,f	0.118±0.01C,d	11.56±0.02A,ab	0.376±0.00B,c
Kilis × 6th month	455.06±1.44B,ab	5.78±0.08B,ab	25.75±0.07A,b	0.817±0.00C,b	0.143±0.00A,a	0.257±0.00A,a	11.31±0.11A,b	0.454±0.00A,b
Mersin × 0th month	401.51±1.82C,c	4.38±0.08B,f	15.95±0.04D,h	0.389±0.00C,f	0.076±0.00C,de	0.182±0.00B,bc	9.07±0.03B,e	0.122±0.00C,f
Mersin × 2nd month	478.89±0.51A,ab	6.40±0.01A,a	24.08±0.12A,a	0.908±0.00A,b	0.109±0.00B,b	0.231±0.00A,ab	11.45±0.01A,b	0.488±0.00B,b
Mersin × 4th month	404.74±1.85C,e	4.40±0.08B,e	16.76±0.04C,h	0.391±0.00C,g	0.070±0.00C,de	0.182±0.00B,c	9.09±0.02B,d	0.124±0.00C,e
Mersin × 6th month	451.53±0.71B,ab	6.19±0.09B,a	21.57±0.11B,g	0.782±0.01B,c	0.134±0.00A,ab	0.215±0.00A,bc	11.47±0.33A,b	0.579±0.00A,a
Kahramanmaraş × 0th month	450.64±0.42B,a	4.60±0.20B,ef	18.38±0.00C,f	0.232±0.00C,g	0.058±0.00B,ef	0.146±0.01C,de	9.67±0.11B,cd	0.210±0.00C,e
Kahramanmaraş × 2nd month	474.57±0.46A,bcd	6.08±0.06A,ab	22.24±0.07A,c	0.848±0.00A,c	0.134±0.00A,a	0.243±0.00A,a	11.72±0.11A,ab	0.392±0.00B,c
Kahramanmaraş × 4th month	455.22±0.29B,bc	6.27±0.09A,a	21.71±0.09B,c	0.787±0.01B,c	0.133±0.00A,a	0.216±0.00B,abc	11.59±0.32A,ab	0.583±0.00A,a
Kahramanmaraş × 6th month	451.38±0.43B,ab	4.65±0.20B,de	22.11±0.00A,f	0.234±0.00C,g	0.063±0.00B,ef	0.146±0.01C,e	9.70±0.11B,e	0.252±0.00C,d
Araban × 0th month	455.70±0.51AB,a	5.50±0.03C,bcd	19.38±0.00C,e	0.542±0.01C,d	0.097±0.00B,cd	0.185±0.00B,bc	9.48±0.10C,de	0.471±0.01B,b
Araban × 2nd month	446.92±2.85C,e	5.66±0.05BC,bc	18.79±0.00D,f	0.456±0.00D,g	0.056±0.00C,c	0.100±0.00C,d	10.87±0.03B,c	0.223±0.00C,d
Araban × 4th month	451.09±1.99BC,c	6.01±0.03AB,abc	22.39±0.10B,b	0.759±0.00B,d	0.120±0.00A,ab	0.229±0.00A,ab	11.72±0.12A,ab	0.523±0.01A,b
Araban × 6th month	460.74±0.55A,a	6.17±0.01A,a	27.88±0.13A,a	0.876±0.00A,a	0.119±0.00A,bc	0.243±0.00A,ab	11.03±0.01B,bc	0.568±0.00A,a
Yavuzeli × 0th month	454.83±1.06A,a	5.92±0.33A,ab	20.59±0.00B,d	0.713±0.00B,c	0.106±0.01A,bc	0.199±0.00B,bc	10.22±0.10B,bc	0.356±0.00B,c
Yavuzeli × 2nd month	413.26±1.91B,f	4.51±0.08B,d	16.40±0.04D,g	0.401±0.00C,h	0.101±0.00A,b	0.185±0.00B,c	9.29±0.04C,e	0.126±0.00C,e
Yavuzeli × 4th month	462.60±0.83A,ab	6.15±0.00A,ab	24.02±0.11A,a	0.887±0.00A,a	0.104±0.00A,bc	0.223±0.00A,ab	11.34±0.02A,b	0.483±0.00A,b
Yavuzeli × 6th month	402.43±1.82C,d	4.40±0.08B,e	19.17±0.05C,i	0.389±0.00C,f	0.082±0.00B,de	0.197±0.00B,cd	9.10±0.02C,f	0.146±0.00C,e
Taşköprü × 0th month	454.46±1.13B,a	5.83±0.05A,ab	21.38±0.06C,c	0.814±0.00A,a	0.130±0.00A,a	0.233±0.00A,a	11.31±0.11B,a	0.373±0.00C,c
Taşköprü × 2nd month	486.53±6.69A,a	5.67±0.04A,b	20.22±0.10D,e	0.770±0.00B,d	0.115±0.00B,ab	0.215±0.00A,abc	12.28±0.11A,a	0.465±0.06A,b
Taşköprü × 4th month	458.67±0.25B,bc	5.84±0.05A,abc	22.21±0.06B,b	0.827±0.00A,b	0.133±0.00A,a	0.236±0.00A,a	11.61±0.11B,ab	0.385±0.00BC,c
Taşköprü × 6th month	455.59±1.07B,ab	5.94±0.33A,ab	24.76±0.01A,c	0.716±0.00C,d	0.117±0.01B,bc	0.219±0.00A,bc	10.28±0.03C,d	0.428±0.00AB,b
Nevşehir × 0th month	434.07±2.80C,b	5.52±0.05B,bc	18.25±0.00C,f	0.443±0.00C,e	0.055±0.00D,ef	0.098±0.00C,f	10.53±0.02A,b	0.219±0.00C,e
Nevşehir × 2nd month	480.11±1.08A,ab	6.63±0.05A,a	22.49±0.01A,c	0.938±0.00A,a	0.137±0.00A,a	0.211±0.00A,abc	10.34±0.03A,cd	0.459±0.00A,b
Nevşehir × 4th month	458.82±1.07B,bc	6.19±0.46A,a	20.77±0.00B,d	0.720±0.00B,e	0.108±0.01B,bc	0.198±0.00AB,bc	10.31±0.10A,c	0.362±0.00B,c
Nevşehir × 6th month	450.49±0.37B,ab	5.14±0.11B,cd	20.95±0.08B,h	0.458±0.00C,e	0.073±0.00C,ef	0.175±0.00B,de	7.53±0.03B,g	0.329±0.00B,c
Ankara × 0th month	447.57±2.04B,a	5.95±0.03A,ab	22.21±0.10A,b	0.756±0.01A,b	0.122±0.00A,ab	0.233±0.00A,a	11.68±0.12A,a	0.515±0.01A,b
Ankara × 2nd month	475.74±0.54A,bc	5.70±0.04AB,b	20.23±0.00B,e	0.562±0.00B,f	0.101±0.00B,b	0.188±0.00B,c	9.80±0.12C,de	0.504±0.02A,b
Ankara × 4th month	470.08±6.51A,a	5.44±0.04B,cd	20.07±0.11B,e	0.754±0.00A,d	0.107±0.00B,bc	0.206±0.00B,abc	12.07±0.12A,a	0.517±0.00A,b
Ankara × 6th month	435.98±3.26C,c	5.53±0.05AB,bc	21.95±0.01A,f	0.780±0.00A,c	0.058±0.00C,f	0.109±0.00C,f	10.56±0.03B,cd	0.259±0.00B,d

(Contd...)

Table 4: (*Continued*)

Factors	K (mgL^{-1})	Ca (mgL^{-1})	Mg (mgL^{-1})	Fe (mgL^{-1})	Cu (mgL^{-1})	Mn (mgL^{-1})	Na (mgL^{-1})	Zn (mgL^{-1})
Aksaray × 0th month	451.04±0.16B,a	6.17±0.09A,a	21.58±0.10C,c	0.171±0.01C,h	0.132±0.00A,a	0.215±0.00B,ab	11.58±0.31B,a	0.577±0.00A,a
Aksaray × 2nd month	465.61±1.23A,cd	5.04±0.07C,cd	23.27±0.01B,b	0.445±0.00B,g	0.040±0.00C,c	0.116±0.01C,d	11.88±0.01B,ab	0.384±0.00B,c
Aksaray × 4th month	437.31±2.89C,d	5.55±0.05B,bcd	19.17±0.00D,g	0.828±0.00A,b	0.055±0.00B,ef	0.099±0.00C,d	10.56±0.02C,c	0.220±0.00C,d
Aksaray × 6th month	448.86±2.19B,b	6.03±0.06AB,ab	24.41±0.11A,d	0.457±0.00B,e	0.128±0.00A,abc	0.254±0.00A,a	12.76±0.14A,a	0.564±0.01A,a
Tokat × 0th month	450.43±0.79B,a	5.09±0.11B,cde	17.36±0.08D,g	0.803±0.00A,a	0.064±0.00D,e	0.160±0.00C,cd	7.52±0.04D,f	0.276±0.00C,d
Tokat × 2nd month	464.79±0.43A,d	6.41±0.10A,a	22.24±0.11B,c	0.546±0.01B,h	0.135±0.00A,a	0.224±0.00A,ab	11.81±0.33A,ab	0.596±0.00A,a
Tokat × 4th month	460.35±0.75A,abc	5.54±0.03B,bcd	19.55±0.00C,f	0.537±0.01B,f	0.098±0.00C,cd	0.186±0.00BC,c	9.55±0.09C,d	0.483±0.01B,b
Tokat × 6th month	456.72±0.52AB,ab	5.47±0.04B,bc	23.31±0.00A,e	0.780±0.01A,c	0.107±0.00B,cd	0.204±0.00AB,cd	11.33±0.12B,b	0.574±0.02A,a
Significanteffects								
E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SP	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
E×SP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*mean±standard error of mean (SEM). 1Capital letters show differences among storage periods in each ecotype, lower letters show differences between ecotypes in each storage period at P ≤ 0.05 error level according to Tukey's test

to potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), sodium (Na), and zinc (Zn). As shown in Table 4, there were significant differences ($P \leq 0.05$) in the macro mineral contents of garlic ecotypes during the experiment. The results on macro mineral contents exhibited that each garlic ecotype displayed an opposite trend in each macro element throughout the storage. Regarding K content, the highest value was recorded in Araban ecotype (455.70 mg L^{-1}) and the lowest was in Mersin ecotype (401.51 mg L^{-1}) at initial. Throughout the storage period, ecotypes Mersin and Nevşehir exhibited an increasing trend, and their values increased by 13% and 4%, respectively. While Yavuzeli and Ankara ecotypes significantly decreased, the other six ecotypes remained constant after 6 months of storage. Unlike the K content, dissimilar behavior was observed in the Ca content of garlic ecotypes (Table 4). A significant reduction (26%) was only determined in the Yavuzeli ecotype. Thereafter, a considerable increase was found in the ecotypes Mersin (41%) and Araban (12%) at the end of the storage compared to initial values. It has been reported that Ca content is positively correlated with better storage capability (Coolong et al., 2008). Various trends were also observed for the Mg content in all garlic ecotypes. Mostly, the Mg content of garlic ecotypes significantly increased; the only exception was the Yavuzeli ecotype, in which the Mg content decreased and exhibited the minimum value (19.17 mg L^{-1}); the Ankara ecotype exhibited the same values with initials after 6 months (Table 4). As can be seen from Table 4, there was a wide variation amongst ecotypes in terms of microelement content. It was also determined that the microelement content showed different trends in each ecotype throughout the storage. The Fe content increased dramatically in ecotypes Aksaray (167%), Mersin (101%), and Araban (61%); decreasing trends in Fe content were observed in ecotypes Yavuzeli and Taşköprü at 45% and 12%, respectively, at the end of the 6th month of storage. In this study, storage periods lead to a decrease or increase in the Cu content of garlic ecotypes except for the Aksaray and Kahramanmaraş during the storage. The increase at an exponential rate was observed in Kilis ecotype (~3-fold) whereas the highest and the lowest reduction were observed in ecotypes Ankara (52%) and Yavuzeli (23%). The Mn content in this study increased in six ecotypes, but a sharp decrease (53%) was observed in the Ankara ecotype on the 6th month of storage. However, the Mn content of the Kahramanmaraş, Yavuzeli, and Taşköprü ecotypes was stable after 6 months of storage. It was observed that Na content increased in ecotypes Mersin, Araban, Aksaray, and Tokat and decreased in ecotypes Yavuzeli, Taşköprü, Nevşehir, and Ankara whereas unchanged in others at the end of the storage. The content of Zn decreased after 6 months of storage in ecotypes

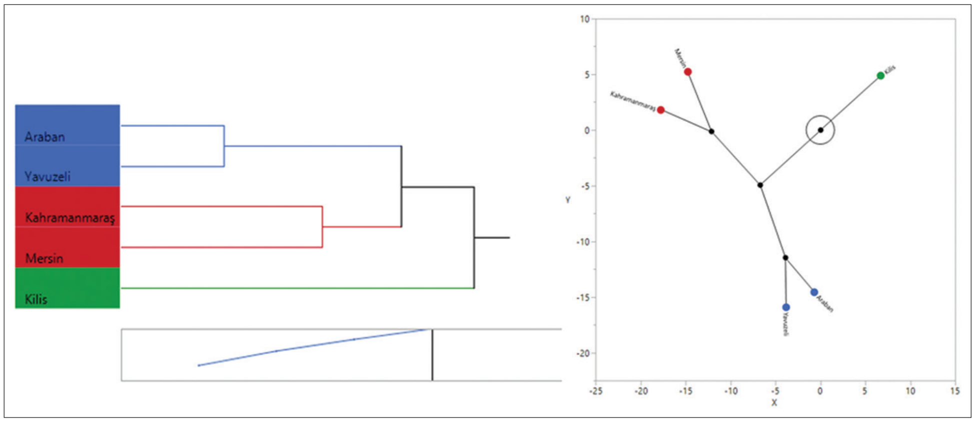

Fig 2. Dendrogram (left) and constellation plot (right) of hardneck type garlic ecotypes based on chemometric characteristics

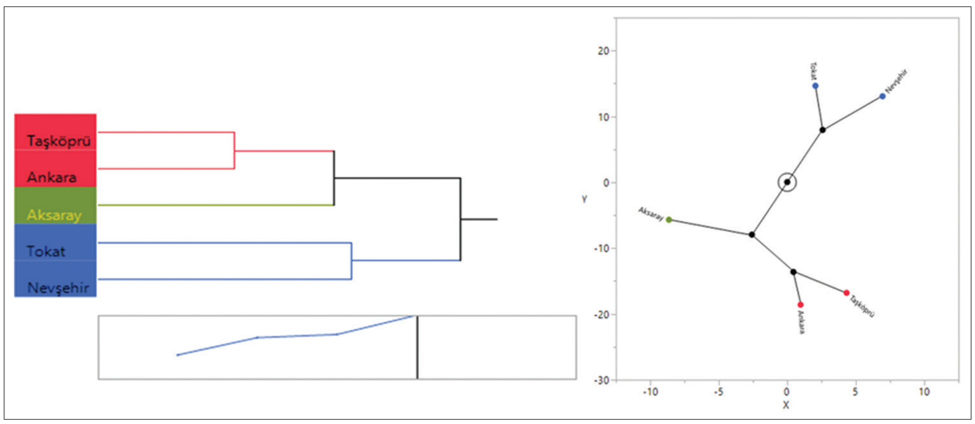

Fig 3. Dendrogram and constellation plot of softneck type garlic ecotypes based on chemometric characteristics

Yavuzeli and Ankara from 0.356 mg L^{-1} to 0.146 mg L^{-1} and from 0.515 mg L^{-1} to 0.259 mg L^{-1}, respectively. However, stored ecotypes Kahramanmaraş and Aksaray were stable in Zn value after 6 months compared to the initial values. On the other hand, the highest increase was observed in the ecotypes Mersin and Tokat demonstrating 3.5- and 1.1-fold increments amongst others. As far as we know, there is scarce or no report on the effect of storage period on mineral composition of garlic bulbs. Consistent with our study, Jolayemi et al. (2018) and Petropoulos et al. (2016) have revealed that mineral response varied depending on genotype and storage duration in onion during storage.

Chemometric classification of hardneck and softneck garlic ecotypes

Hierarchical clustering analysis (HCA) was used to illustrate the relationship structure of five hardneck garlic ecotypes (Kilis, Mersin, Kahramanmaraş, Araban and Yavuzeli) and five softneck garlic ecotypes (Taşköprü, Nevşehir, Ankara, Aksaray and Tokat). Based on the ward aggregation distances, similarity (relationship) was determined from 14 different quality attributes including SSC and ash content, TA, pH, AOC, TPC and macro and micro minerals (K, Ca, Mg, Fe, Cu, Mn, Na and Zn). In addition, the constellation plot shows group/cluster relationships as well as dendrograms. The dendrograms (Fig. 2 and 3) revealed a clear separation between hardneck and softneck garlic ecotypes. These present two major clusters and, in each cluster, shows the existence of diversity and similarity in the ecotypes based on the quality attributes.

As seen in Fig. 2, 'cluster I' comprised of Kilis ecotypes. The other cluster (cluster II) contained four ecotypes including Araban, Yavuzeli, Kahramanmaraş, and Mersin. According to the results, it can be noted that the ecotypes Araban and Yavuzeli have the same origin based on the closest relationship between them. Likewise, as depicted in Fig. 3 by setting a suitable number of clusters, two main clusters were identified. The ecotypes Taşköprü, Ankara and Aksaray were grouped in cluster I. In addition, cluster II consisted of ecotypes Tokat and Nevşehir.

CONCLUSIONS

Irrespective of the ecotype, the magnitude of change in quality attributes was affected by the storage period. While weight loss, sprouting ratio, and titratable acidity increased, pH and antioxidant capacity decreased.

Although SSC, ash content, total phenolic content, and macro-mineral content were influenced by the storage period, these traits did not change regularly throughout the storage. Furthermore, rooting, and waxy breakdown were not observed in each storage period. The results obtained in this paper also indicate that there is a significant difference ($P \leq 0.05$) among the ecotypes for all the traits. According to the results of experiments, the storage period is one of the most important factors for garlic storage in terms of showing a different tendency for all ecotypes in each storage period. The ecotypes Taşköprü, Tokat, Nevşehir, and Ankara exhibited the best performance based on the analyzed quality attributes of garlic throughout the storage. It can be concluded that softneck garlic ecotypes seem to contribute to higher biochemical and physical quality traits than hardneck garlic ecotypes. Therefore, these promising ecotypes could be used for multiple purposes. Hence, these softneck ecotypes can be improved further in developing durable planting material with minimum storage losses. In conclusion, this study provides initial information describing the considerable varietal differences in the quality attributes of hardneck and softneck garlic ecotypes in long-term storage. Also provides evidence for the first time on the existence of superior ecotypes that can satisfy garlic export criteria.

Authors Contributions

Selen Akan: Conceptualization, methodology, validation, formal analysis, investigation, data curation, writing - original draft, writing - review and editing, visualization, supervision.

Faika Yaralı Karakan: Conceptualization, methodology, validation, formal analysis, investigation, writing-review and editing.

Özge Horzum: Conceptualization, methodology, validation, formal analysis, investigation, writing-review and editing.

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