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Valley Natural Storage in Kütdiken Lemon is as Effective as Volcanic Natural Storage*

Kütdiken Limonu'nda Vadi Doğal Depolama, Volkanik Doğal Depolama Kadar Etkilidir

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Abstract: Increasing food demand is a pressing issue due to global food waste and population growth. In Türkiye, high humidity in the volcanic storage of Ortahisar leads to significant postharvest losses of lemons. This study aims to highlight the storage advantages of Kütdiken lemons by comparing the conditions in Bolu's wide valley with those in Ortahisar. The lemons were stored in three environments: a mechanized cold storage, volcanic tuff storage, and valley storage in Bolu. Temperature and humidity were monitored with data loggers, while weight loss, decay rate, and quality characteristics were assessed periodically.The results indicated that both storage duration and environment significantly impact Kütdiken lemons. On the 30th day, weight loss was 6.03%, increasing to 10.27% by the 120th day. The lowest weight loss occurred in controlled conditions (5.90%), while the highest (6.64%) was in valley storage. The decay rate was lowest at 2.12% in controlled storage and highest at 2.74% in valley storage. Juice content was measured at 30.16% on day 30 and 35.06% on day 120, with volcanic storage yielding the lowest juice content (30.92%) and controlled storage the highest (32.79%). In conclusion, Bolu's favorable climate and logistical ease to markets like Istanbul and Ankara suggest that natural valley storage for lemons could be a viable alternative. Establishing natural storage facilities in this region could enhance capacity and competitiveness.

Keywords: Kütdiken Lemon, Natural Storage, Volcanic Storage, Weight Loss, Fruit Quality

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Öz: Artan gıda talebi, küresel gıda israfı ve nüfus artışı nedeniyle önemli bir sorun haline gelmiştir. Türkiye'de, Ortahisar'daki volkanik depolama alanında yüksek nem, limonlarda önemli postharvest kayıplara yol açmaktadır. Bu çalışma, Kütdiken limonlarının depolama avantajlarını, Bolu'nun geniş vadi koşulları ile Ortahisar'daki koşulları karşılaştırarak vurgulamayı amaçlamaktadır. Limonlar, üç farklı ortamda depolanmıştır: mekanize soğuk depolama, volkanik tüf depolaması ve Bolu'daki vadi depolaması. Sıcaklık ve nem, veri kayıt cihazları ile izlenmiş, ağırlık kaybı, bozulma oranı ve kalite özellikleri belirli aralıklarla değerlendirilmiştir. Sonuçlar, hem depolama süresinin hem de ortamın Kütdiken limonları üzerinde önemli etkileri olduğunu göstermiştir. 30. günde ağırlık kaybı %6.03, 120. günde ise %10.27'ye çıkmıştır. En düşük ağırlık kaybı kontrollü koşullarda (%5.90), en yüksek kayıp ise vadi depolamasında (%6.64) gözlemlenmiştir. Bozulma oranı, kontrollü depolamada %2.12 ile en düşük, vadi depolamasında %2.74 ile en yüksek olmuştur. Meyve suyu içeriği, 30. günde %30.16, 120. günde ise %35.06 olarak ölçülmüştür; volkanik depolama en düşük meyve suyu içeriğini (%30.92) verirken, kontrollü depolama en yüksek (%32.79) içeriği sağlamıştır. Sonuç olarak, Bolu'nun uygun iklimi ve İstanbul ile Ankara gibi pazarlara lojistik kolaylığı, limonlar için doğal vadi depolamasının uygun bir alternatif olabileceğini göstermektedir. Bu bölgede doğal depolama tesislerinin kurulması, kapasiteyi artırarak rekabetçiliği geliştirebilir.

Anahtar Kelimeler: Kütdiken Limonu, Doğal Depolama, Volkanik Depolama, Ağırlık Kaybı, Meyve Kalitesi

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INTRODUCTION

More than 1.3 billion tons of food are lost or wasted annually worldwide. With the increasing population, wastage is increasing. By 2050, it is predicted that the world population will be 9.7 billion and the need for food will increase by 60% in parallel. This is why food safety emerges as an issue that needs urgent intervention (United Nations [UN] Türkiye, 2025). The high cost of cold storage on the product due to high energy inputs has increased the demand for natural cold storage. Temperature and humidity cannot be controlled during the storage of products in naturally cooled warehouses. These warehouses store mostly root vegetables, apples, lemons, and potatoes (Özdemir and Çandır, 2017).

A total of 70% of lemon fruits in Turkey are grown in Mersin. Lemons suitable for storage are harvested in December and stored in ordinary warehouses on the Mersin coastline until March, and when the weather warms up, they are transported to Ortahisar town of Nevşehir province Ürgüp district or to naturally cooled warehouses in the highlands close to the production area. Approximately 85% of the lemons produced are stored in Ortahisar (Canan and Ağar, 2006). The temperature values of Ortahisar warehouses are very suitable for lemon storage, but other quality criteria and post-harvest losses are quite high. The reason for this is the high relative humidity in the warehouses and the insufficient evacuation of the warehouse air (Canan et al., 2015). Ortahisar is a town built on volcanic tuff soils erupted by Mount Erciyes. The feature of tuff is although it is soft enough that any person can open a large cave with a hand pickaxe; It hardens after contact with air and allows very useful caves to be made (Canan and Ağar, 2006).

Kütdiken lemon is in the Feminello subgroup of the Eureka group. This variety, like all lemons, originates in Italy. However, there is no information about his being brought to Turkey. Over time, it has become a lemon variety unique to Turkey and is the most produced lemon type in our country. The udder part is underdeveloped, the shell is tightly attached to the smooth and shiny flesh. It is the most superior and high-quality variety in the world in terms of internal quality, water, and odor characteristics. It is high quality. It is a high-yielding variety that does not show periodicity and is the most stored lemon in Turkey. The trees grow in medium strength, and the distribution of fruits on the tree is uniform (Kafa, 2015). Lemon fruit (*Citrus limon*) is one of the commonly consumed fruits used directly or in soft drinks, alcoholic beverages, and meals (Shimizu et al., 2019). Lemon polyphenols prolong life, delay aging lesions, and reduce obesity. Lemon fruit is also rich in citric acid, vitamin C, and polyphenols, which have benefits such as alleviation of fatigue (Kajimoto et al., 2007) and lipid-lowering effects (Miyake et al., 2006; Hiramitsu et al., 2014).

Bolu province, which has a lot of suitable valleys for natural storage, is 743 m above sea level with an annual average temperature of 10.4 °C. Nevşehir Province, where Ortahisar is located, has an altitude of 1260 m and an average temperature of 10.7 °C (General Directorate of Meteorology, 2025), with a volcanic rhizosphere. Generally, the temperature 2 m below is equal to the annual average temperature above the ground and is generally constant throughout the year (Kader, 2002). Considering the example of Bolu and Nevşehir with this principle, it is thought that Bolu is equal to or slightly more advantageous than Nevşehir in terms of underground storage temperatures. If natural storage is combined with electricity and technological facilities, the energy costs needed will be less.

This study aimed to determine the possibility of reflecting the aforementioned superior features of a valley in Bolu province to natural storage by comparing it with the natural storage of Kütdiken lemon, which is the most stored and traded variety in Türkiye, in Ortahisar conditions.

MATERIAL AND METHOD

The Kütdiken lemon (*Citrus lemon*) variety was used in the experiment. This variety is convenient for storage and transportation. Due to its suitability for long-term storage, it can be stored until the export demand rises. Fruit skin color is light green-yellow or lemon yellow. The bark is smooth, shiny, and tightly attached. The mammary part is not well developed and is not obvious. Its fruits are elliptical. It contains 32.96% fruit juice at maturity. The acid rate is 7.16%. The number of seeds per fruit is 10-11. It has a strong tree canopy and is a mid-season variety. The fruits best suited for storage are those harvested before the November rains. Harvest continues until February under favorable conditions (Tuzcu, 1990).

Since there is no natural cold storage in Bolu yet, the underground warehouse used as a potato storage 2 meters below was considered as cold storage in this study. The average temperature is around 10 ℃, and humidity varies between 85-95%. These warehouses are completely earthen and surrounded by wood. Since the village houses have been replaced by reinforced concrete structures today, the number of such warehouses is gradually decreasing.

Lemon fruits were purchased from an orchard in Mersin (Erdemli) region from approximately 20 years old trees grafted on *Citrus* (*Citrus aurantium*) trees on 1 January. Fruits were separated according to their color, size, and quality. Approximately the same color, medium-sized, and undamaged fruits were selected and placed in wooden boxes, which are commercial crates commonly used for storage in the market.

In the experiments, the cold storage in controlled conditions at Bolu Abant Izzet Baysal University (BAIBU), the ordinary warehouse in Ortahisar as the volcanic tuff storage, and the valley storage in Bolu were used. Temperature and humidity are recorded with data loggers (DS102 Heat and Humidity Datalogger, Ecowitt, Hong Kong) in the warehouses, including on-site. Thermomechanical storage is kept constant at 10 ℃ for lemon. Since it is not controlled in ordinary warehouses, humidity control was not carried out in the controlled warehouse either. The fruits were stored for 120 days, and analyses were conducted every 30 days.

The lemons included in the experiment were numbered before being put into the warehouses and their initial weights were weighed one by one with a precision digital scale (Precisa 125 ASCS, Switzerland). During the storage period in the warehouse, 10 fruits were taken once a month and weighed again and the weight loss was calculated according to the formula below (1).

$$\text{Weight Loss (\%)} = [(\text{Initial Weight (g)} - \text{Final Weight (g)}) \times 100] \times [\text{Initial Weight (g)}]^{-1} \quad (1)$$

The fruits taken during the storage period were examined and the decay rate (DR) was recorded as the total amount of rotten fruit. The amount of rotten fruit counted was calculated as the estimated percentage of total fruit according to the formula below (2).

$$\text{DR (\%)} = [\text{Rotten Fruits (pieces)} \times 100] \times (\text{Total Fruits})^{-1} \quad (2)$$

In the monthly counting and measurement processes, the green capsule fruits (GCF) were counted and the percentage of the total number of fruits in the box was calculated according to the formula below (3).

$$\text{GCF (\%)} = [\text{Number of GCF} \times 100] \times (\text{Total Number of Fruits})^{-1} \quad (3)$$

The weight of the pulp was subtracted from the initial period of the fruit and the percentage divided by the weight of the fruit taken as a sample was calculated according to the formula below(4).

$$\text{Fruit Juice(\%)} = [(\text{Fruit Weight} - \text{Pulp Weight}) \times 100] \times \text{Fruit Weight}^{-1} \quad (4)$$

After the pulp was filtered, 1 ml of the extract from the filtrate was immersed in the glass electrode sample of the pH meter (pH3110, WTW, Germany) and titrated with 0.1 N NaOH until the pH value was 8.1 with continuous stirring using a magnetic stirrer (Dündar and Pekmezci, 1991), and was calculated with the equation below.

TA (g/100ml) = [NaOH spent x Normality of NaOH x factor of NaOH x 0.007 x100] x [Amount of Sample Taken (ml)]$^{-1}$ (5)

The solible solid (SS) was determined by a hand-type refractometer (Atago N-20 Brix 0-20 %, Japan) after the pulp was filtrated. The maturity index (%) was calculated by dividing the SS to the TA and multiplying by 100 (Cemeroğlu, 1992).

The visiual quality (VQ) of lemon fruits at the end of the storage period was evaluated by ten different sensory panelists, who scored them from 1 to 5 in terms of the general view. Visual Quality, a scale of 1 indicating the worst and 5 is the best.

Color properties were determined according to CIELAB with a hand-type colorimeter (NR60CP, 3Nh Tech, Shenzen, China).

The experiment was designed in factorial design with two factors, storage duration and storage conditions in triplicates. Data were subjected to two-way ANOVA to determine the significance of the factors and their interaction. When F was significant, data were subjected to Tukey's post-hoc test (HSD) to compare means. The interrelationship between traits and factors were determined by a principal component analysis (PCA). Correlations among the traits were determined by Pearson's pairwise correlations using "corrplot" package of R Studio (Wei and Simko, 2017).

RESULTS AND DISCUSSION

The average storage temperature gradually increased from 7.57 ℃ to 9.20 ℃ from January to May in the warehouse in the volcanic region (Ortahisar). The relative humidity values in the same warehouse varied between 95.60% (January; 0th day) and 98.70% (May; 120th day). While the temperature values in the warehouse in the valley (Bolu) were 8.10 ℃ on average in January, it reached an average of 13.50 ℃ in May. The relative humidity in this warehouse varied between 69.24% (January) and 81.00% (March; 60th day). The temperature and relative humidity values of the warehouses during the study are presented in Table 1.

Table 1. Temperature (Temp; ℃) and relative humidity (RH; %) values in different storages during experiment.
Çizelge 1. Deney sırasında farklı depolardaki sıcaklık (Temp; ℃) ve bağıl nem (RH; %) değerleri.

			Valley warehouse		Volcanic warehouse
Months		Temp (℃)	RH (%)	Temp (℃)	RH (%)
January	Min	9.40	76.00	8.60	99.00
	Max	6.60	60.00	7.00	68.00
	Avg	8.10	69.24	7.57	95.60
February	Min	13.00	81.00	9.50	99.00
	Max	6.50	71.00	7.00	70.00
	Avg	9.20	76.83	7.80	97.40
March	Min	13.90	78.11	11.00	99.00
	Max	9.70	73.00	5.10	91.00
	Avg	11.88	81.00	8.60	98.32
April	Min	15.40	84.00	11.50	99.00
	Max	11.20	64.00	6.70	91.00
	Avg	13.02	73.73	9.01	98.00
June	Min	15.80	82.00	13.90	99.00
	Max	12.60	70.00	9.20	84.00
	Avg	13.50	76.82	9.20	98.70

*Commercial warehouse is a mechanized cold storage. The temperature was kept constant at 10 ℃.

The changes observed in weight loss during the storage of Kütdiken lemon are given in Table 2. Weight loss significantly varied according to the storage periods. The mean weight loss was 6.03% on the 30th day, 7.19% on the 60th day, 8.04% on the 90th day, and 10.27% on the 120th day. Although the weight loss varies between warehouses, there was no significant difference. In addition, the highest average weight loss occurred in valley natural warehouse at 6.64%, while the lowest weight loss (5.90%) was in controlled conditions. The storage period and warehouse interactions were significant in terms of weight loss. The

lowest weight loss was in controlled conditions in all storage periods, while the highest values were altered between valley and volcanic storages throughout the storage periods (Table 2).

Table 2. Kutdiken lemon pomological parameters in different storages at postharvest.
Çizelge 2. Kutdiken limonunun hasat sonrası farklı depolardaki pomolojik parametreleri.

		WL (%)	DR (%)	FGC (%)	FJ (%)	TA(%)
Storages						
Controlled		5.90 ± 0.89 ns	2.12 ± 0.53ns	66.18 ± 5.55 a	32.79 ± 0.64ns	7.43 ± 0.38ns
Valley		6.64 ± 0.98	2.74 ± 0.57	74.81 ± 4.11 ab	32.20 ± 0.83	7.76 ± 0.34
Volcanic		6.38 ± 0.93	2.67 ± 0.55	75.22 ± 4.08 b	30.92 ± 0.51	7.73 ± 0.33
Storage periods (day)						
0		0.00 ± 0.00 d	0.00 ±0.00 b	100.00 ± 0.00 a	30.16 ± 0.00 c	9.46 ± 0.00 a
30		6.03 ± 0.25 c	2.00 ±0.17 ab	79.18 ± 2.46 b	30.16 ± 0.57 c	7.45 ± 0.13 c
60		7.19 ± 0.27 b	2.87 ±0.20 a	67.34 ± 2.57 c	31.12 ± 0.89 bc	5.89 ± 0.10 e
90		8.04 ± 0.31 b	3.65 ±0.13 a	59.71 ± 2.01 cd	33.35 ± 0.49 ab	8.64 ± 0.10 b
120		10.27 ± 0.25 a	4.02 ±1.16 a	54.11 ± 3.96 d	35.06 ± 0.84 a	6.75 ± 0.16 d
Storages × Storage periods						
0	-	0.00 ± 0.00 f	0.00 ± 0.00 ns	100.00 ± 0.00 a	30.16 ± 0.00 bcd	9.46 ± 0.00 a
	Controlled	5.72 ± 0.59 e	1.34 ± 0.03	72.15 ± 4.04 bcd	31.95 ± 0.51 bcd	7.45 ± 0.12 cd
30	Valley	6.35 ± 0.12 cde	2.42 ± 0.08	82.00 ± 2.89 abc	29.00 ± 0.74 d	7.60 ± 0.29 c
	Volcanic	6.02 ± 0.51 de	2.25 ± 0.10	83.40 ± 3.23 ab	29.52 ± 0.76 cd	7.30 ± 0.29 cd
	Controlled	6.37 ± 0.22 cde	2.11 ± 0.08	60.02 ± 5.79 de	32.97 ± 1.90 a-d	5.54 ± 0.08 f
60	Valley	7.87 ± 0.35 cd	3.21 ± 0.19	71.40 ± 0.92 bcd	31.44 ± 1.32 bcd	6.10 ± 0.12 ef
	Volcanic	7.34 ± 0.32 cde	3.28 ± 0.10	70.60 ± 2.08 bcd	28.96 ± 0.15 d	6.03 ± 0.03 ef
	Controlled	7.42 ± 0.25 cde	3.18 ± 0.08	55.45 ± 3.87 de	34.15 ± 1.24 abc	8.43 ± 0.07 b
90	Valley	8.34 ± 0.90 bc	3.90 ± 0.12	60.40 ± 3.84 de	33.26 ± 0.11 a-d	8.86 ± 0.17 ab
	Volcanic	8.37 ± 0.11 bc	3.88 ± 0.05	63.30 ± 1.71 cd	32.64 ± 0.84 a-d	8.64 ± 0.19 b
	Controlled	9.98 ± 0.65 ab	3.95 ± 2.28	43.30 ± 9.15 e	34.72 ± 1.58 ab	6.28 ± 0.18 ef
120	Valley	10.65 ± 0.45 a	4.16 ± 2.40	60.25 ± 3.04 de	37.15 ± 1.33 a	6.76 ± 0.05 de
	Volcanic	10.17 ± 0.17 ab	3.95 ± 2.28	58.78 ± 2.59 de	33.31 ± 0.65 a-d	7.21 ± 0.22 cd
ANOVA						
$F_{(Storages)}$		0.57ns	0.08ns	0.94ns	1.73ns	2.26ns
$F_{(Period)}$		273.56***	7.11***	72.54***	15.32***	258.42***
$F_{(Period×Storage)}$		4.35*	0.54ns	9.47***	5.01*	6.67**

Note: Each value is presented as the mean ± standard error of three replicates. Within each column, means followed by different symbols indicate significant differences according to the LSD test at $p < 0.05$, where ***, **, * denote significant differences at $p \leq 0.0001$, 0.001, and 0.05 levels, respectively. WL: Weight loss, RF Rotten fruit, FGC: Green capsuled fruit, FJ: Fruit juice, TA: Titratable acidity

Decay rate (DR), also known as decay losses, during storage is as crucial as weight loss. As the storage period of lemons extends, an increase in DR is observed (Table 2). The minimum decay loss occurred in the controlled warehouse (2.12%), while the maximum decay loss was identified in the natural warehouse (2.74%), and no significant difference in DR among warehouses was found. Upon scrutinizing Table 2, DR are highest in 120th day (4.02%) and lowest in 30th day (2%), with a significant difference between months. Furthermore, decay losses increased with prolonged storage.

Another storage criterion, the quantity of green-capsuled fruit (FGC), being high, signifies a reduction in commercial losses. A significant portion of the decay in *Citrus* fruits occurs after the green capsule turns brown. Throughout storage, all fruits for each application and repetition were examined, and green-capsuled, brown, and dried fruits, as well as those without capsules, were identified. The rates of green-capsuled fruit were determined. Changes in the quantity of green-capsuled fruit during the storage of the Kütdiken lemon variety are presented in Table 2. The most significant decrease in the proportion of FGC occurs in 30th day (79.18%), with the initial rate of 100% FGC dropping to approximately 54.11% in 120th day. The green-capsuled fruit rates were calculated 79.18% in 30th day, 67.34% in 60th day, 59.72% in 90th day, and 54.11% in 120th day. At the end of the storage period, the average rate in volcanic warehouse was measured as the highest at 75.22%, while the lowest was recorded in the controlled warehouse at an average

of 66.18%. The difference between warehouses is significant ($p < 0.05$), indicating that the reduction in the proportion of FGC is slower in the controlled warehouse.

The results demonstrate that the fruit juice content (FJ) of Kütdiken lemons significantly varies over the storage period, as detailed in Table 2 ($p < 0.05$). On the 30th day, the FJ was measured at 30.16%, reaching 35.06% by the 120th day. Although controlled storage showed the highest FJ at 32.79%, while volcanic storage exhibited the lowest at 30.92%, there was no statistically significant difference in FJ levels among the different storage conditions ($p < 0.05$). This indicates that while the storage period influences the FJ, the type of storage does not produce a significant differential effect.

Table 3. Kutdiken lemon's pomological parameters in different storages at postharvest.
Çizelge 3. Kutdiken limonunun hasat sonrası farklı depolardaki pomolojik parametreleri.

		SS (%)	SS/TA	VQ (1-5)
Storages				
Controlled		9.98 ± 0.22ns	1.40 ± 0.09ns	3.93 ± 0.21ns
Valley		9.87 ± 0.17	1.31 ± 0.07	3.67 ± 0.21
Volcanic		10.12 ± 0.21	1.35 ± 0.08	4.47 ± 0.17
Storage periods (day)				
0		9.30 ± 0.00 b	0.98 ± 0.00 d	5.00 ± 0.00 a
30		10.42 ± 0.26 a	1.40 ± 0.03 b	4.11 ± 0.26 b
60		10.72 ± 0.20 a	1.82 ± 0.04 a	3.67 ± 0.17 b
90		10.18 ± 0.11 a	1.18 ± 0.02 c	3.78 ± 0.28 b
120		9.33 ± 0.18 b	1.39 ± 0.04 b	3.56 ± 0.24 b
Storages × Storage periods				
0	-	9.30 ± 0.00 cd	0.98 ± 0.00 f	5.00 ± 0.00 a
30	Controlled	10.93 ± 0.47 ab	1.47 ± 0.08 bc	4.00 ± 0.00 ab
	Valley	10.40 ± 0.50 a-d	1.37 ± 0.03 cde	3.33 ± 0.33 b
	Volcanic	9.93 ± 0.29 a-d	1.36 ± 0.04 cde	5.00 ± 0.00 a
60	Controlled	10.66 ± 0.07 abc	1.92 ± 0.02 a	4.00 ± 0.00 ab
	Valley	10.33 ± 0.33 a-d	1.70 ± 0.06 ab	3.33 ± 0.33 b
	Volcanic	11.16 ± 0.43 a	1.85 ± 0.06 a	3.67 ± 0.33 ab
90	Controlled	10.00 ± 0.00 a-d	1.19 ± 0.01 def	3.33 ± 0.33 b
	Valley	10.00 ± 0.00 a-d	1.13 ± 0.02 ef	3.33 ± 0.33 b
	Volcanic	10.53 ± 0.24 abc	1.22 ± 0.05 c-f	4.67 ± 0.33 ab
120	Controlled	9.00 ± 0.23 d	1.44 ± 0.07 cd	3.33 ± 0.67 b
	Valley	9.33 ± 0.33 cd	1.38 ± 0.05 cd	3.33 ± 0.33 b
	Volcanic	9.66 ± 0.33 bcd	1.34 ± 0.08 cde	4.00 ± 0.00 ab
ANOVA				
$F_{(\text{Storage conditions})}$		0.94ns	4.25*	10.18***
$F_{(\text{Storage period})}$		15.71***	127.60***	12.59***
$F_{(\text{Period x condition})}$		1.74ns	1.27ns	2.23ns

Note: Each value is presented as the mean ± standard error of three replicates. Within each column, means followed by different symbols indicate significant differences according to the LSD test at $p < 0.05$, where ***, **, * denote significant differences at $p \leq 0.0001$, 0.001, and 0.05 levels, respectively. SS: Soluble Solids, SS/TA: Soluble Solids / Titratable Acidity, VQ: Visual Quality, a scale of 1 indicating the worst and 5 is the best.

Changes in the titratable acidity are presented in Table 2. Upon examining the results of the analysis of variance for the changes in titratable acidity, a significant difference is observed among months ($p < 0.05$), while there is no significant difference among warehouses. The titratable acidity is highest at the beginning, calculated as 9.46%, and lowest in 60th day with 5.89%. Titratable acidity decreased in 30th day and 60th day, increases again in 90th day, and decreases again in 120th day. From a warehouse perspective, controlled warehouse was at 7.43%, valley natural warehouse at 7.76%, and volcanic warehouse at 7.73% (Table 2).

The soluble solid (SS) was calculated as an average of 10.42% in 30th day, 10.72% in 60th day, 10.18% in 90th day, and 9.33% in 120th day, which was not significant. The highest SS was measured in volcanic

warehouse as 10.12%, while the lowest was in valley natural warehouse as 9.87%. Although different amounts of SS were measured among warehouses, the differences were not significant (Table 3).

The SS to acidity ratio (SS/TA) is one of the maturity factors in fruits. This ratio, initially 0.98, was observed at its highest in 60th day as 1.92 in the controlled warehouse. The average SS/TA ratio was highest in the controlled warehouse (1.40) and lowest in the valley natural warehouse (1.31). However, no significant difference was observed among warehouses (Table 3).

Lemons stored in the volcanic warehouse exhibited a better visual quality (VQ) but scores were not significantly different. The VQ score decreased with prolonged storage. The value, initially 5, has decreased to 3.56 by the 120th day of storage. Even on the 120th day, the overall appearance of all lemons remains in good condition (Table 3).

The color values of Kütdiken lemon (L*, a*, b*, hue^{o}, Chroma*) did not change significantly among warehouses. The L* value initially was 68.19, then increased slightly to 73.15 on the 30th day, rapidly decreased to 24.60 on the 60th day, remained at a similar level around 24.79 on the 90th day, and increased again to 72.38. The a* value initially was 12.52 and remained the same at 13.36 on the 30th day, rapidly decreased to 1.15 on the 60th day, remained at a similar level around 1.22 on the 90th day, and increased again to 15.84. The b* value initially was 48.48, slightly increased to 53.17 on the 30th day, rapidly decreased to 0.63 on the 60th day, remained at a similar level around 0.70 on the 90th day, and increased again to 47.98. The Chroma* value initially was 75.52, slightly decreased to 55.23 on the 30th day, rapidly decreased to 1.32 on the 60th day, remained at a similar level around 1.41 on the 90th day, and increased again to 50.59 on the 120th day. The hue value initially was 50.08, then slightly increased to 76.18 on the 30th day, rapidly increased to 208.75 on the 60th day, remained at a similar level around 209.59 on the 90th day, and then decreased again to 71.59 (Table 4).

Table 4. Kutdiken lemon's colorimetric parameters in different storages at postharvest.
Çizelge 4. Kutdiken limonunun hasat sonrası farklı depolardaki kolorimetrik parametreleri.

		L*	a*	b*	Chroma*	hue^{o}
Storages						
Controlled		51.82 ± 5.97ns	10.45 ± 2.44ns	30.40 ± 6.57ns	37.60 ± 8.22ns	121.67 ± 19.24ns
Valley		53.09 ± 6.23	8.56 ± 1.68	30.54 ± 6.53	37.00 ± 8.07	123.52 ± 18.80
Volcanic		52.96 ± 6.21	7.44 ± 1.47	29.63 ± 6.37	35.84 ± 7.94	124.52 ± 18.72
Storage periods (day)						
0		68.19 ± 0.28 b	12.52 ± 0.04 a	48.48 ± 0.18 b	75.52 ± 0.09 a	50.08 ± 0.17 c
30		73.15 ± 1.31 a	13.36 ± 2.71 a	53.17 ± 0.92 a	55.23 ± 1.28 b	76.18 ± 2.57 b
60		24.60 ± 0.03 c	1.15 ± 0.02 b	0.63 ± 0.01 c	1.32 ± 0.02 d	208.75 ± 0.68 a
90		24.79 ± 0.02 c	1.22 ± 0.02 b	0.70 ± 0.02 c	1.41 ± 0.02 d	209.59 ± 0.61 a
120		72.38 ± 1.17 a	15.84 ± 0.71 a	47.98 ± 1.49 b	50.59 ± 1.37 c	71.59 ± 1.07 b
Storages × Storage						
0	-	68.19 ± 0.56 a	12.52 ± 0.08 ab	48.48 ± 0.36 ab	75.52 ± 0.18 a	50.08 ± 0.34 c
30	Controlled	70.64 ± 3.39 a	20.44 ± 6.94 a	55.27 ± 2.00 a	59.79 ± 0.92 b	69.89 ± 6.85 b
	Valley	73.81 ± 1.83 a	11.17 ± 0.60 ab	52.31 ± 0.22 ab	53.47 ± 0.17 c	77.94 ± 0.67 b
	Volcanic	75.00 ± 0.85 a	8.47 ± 0.33 bc	51.94 ± 1.66 ab	52.43 ± 1.73 c	80.70 ± 0.33 b
60	Controlled	24.57 ± 0.01 b	1.15 ± 0.04 c	0.62 ± 0.01 c	1.31 ± 0.03 d	208.21 ± 1.00 a
	Valley	24.53 ± 0.01 b	1.21 ± 0.01 c	0.63 ± 0.02 c	1.36 ± 0.00 d	207.45 ± 0.64 a
	Volcanic	24.70 ± 0.06 b	1.10 ± 0.03 c	0.65 ± 0.02 c	1.28 ± 0.02 d	210.60 ± 1.21 a
90	Controlled	24.80 ± 0.05 b	1.22 ± 0.03 c	0.71 ± 0.04 c	1.42 ± 0.05 d	210.23 ± 0.58 a
	Valley	24.83 ± 0.03 b	1.19 ± 0.04 c	0.71 ± 0.03 c	1.40 ± 0.01 d	210.41 ± 1.36 a
	Volcanic	24.75 ± 0.01 b	1.26 ± 0.03 c	0.67 ± 0.02 c	1.42 ± 0.02 d	208.13 ± 0.82 a
120	Controlled	70.88 ± 2.60 a	16.94 ± 1.03 ab	46.92 ± 3.52 b	49.94 ± 3.24 c	69.94 ± 1.93 b
	Valley	74.10 ± 0.61 a	16.69 ± 0.27 ab	50.58 ± 0.61 ab	53.26 ± 0.59 c	71.73 ± 0.33 b
	Volcanic	72.16 ± 2.58 a	13.87 ± 1.41 ab	46.43 ± 2.97 b	48.56 ± 2.38 c	73.09 ± 2.74 b
ANOVA						
$F_{(Storages)}$		1.21ns	3.36*	0.62ns	2.92ns	2.42ns
$F_{(Period)}$		968.62***	43.47***	1143.25***	2487.29***	4333.62***
$F_{(Period×Storage)}$		0.65ns	2.23ns	0.95ns	3.24**	1.61ns

Note: Each value is presented as the mean ± standard error of three replicates. Within each column, means followed by different symbols indicate significant differences according to the LSD test at $p < 0.05$, where ***, **, * denote significant differences at $p \leq 0.0001$, 0.001, and 0.05 levels, respectively.

The chroma value was inversely proportional to weight loss. As the amount of fruit juice increased, weight loss also increased. The dry matter content and weight loss increased, and as a result, the hue value also increased. SS was inversely proportional to L*, a*, b* values, and particularly to chroma. Titratable acidity was negatively correlated to weight loss (r=-0.63***) and SS (-0.34*). Weight loss was the most correlated value with decay (r=0.66), followed by fruit juice quantity (r=0.53). The increment in decay loss was in line with these two characteristics. FGC was negatively correlated to decay, fruit juice quantity, and especially weight loss, while positively correlated to chroma and TA. VQ score was correlated to acidity, chroma, L, and especially FGC, and was negatively correlated to fruit juice quantity, rotten fruit quantity, and especially weight loss (Figure 1).

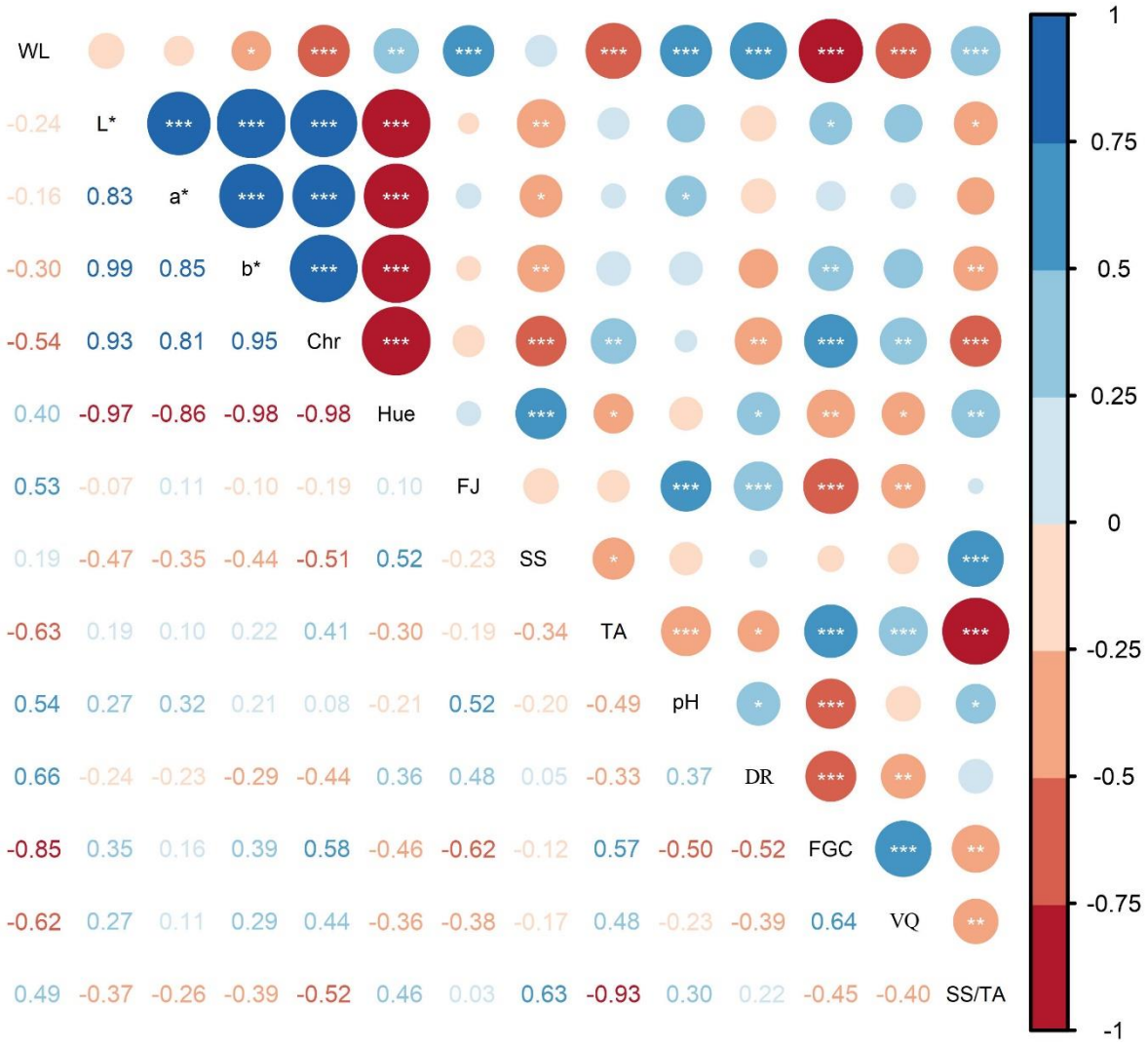
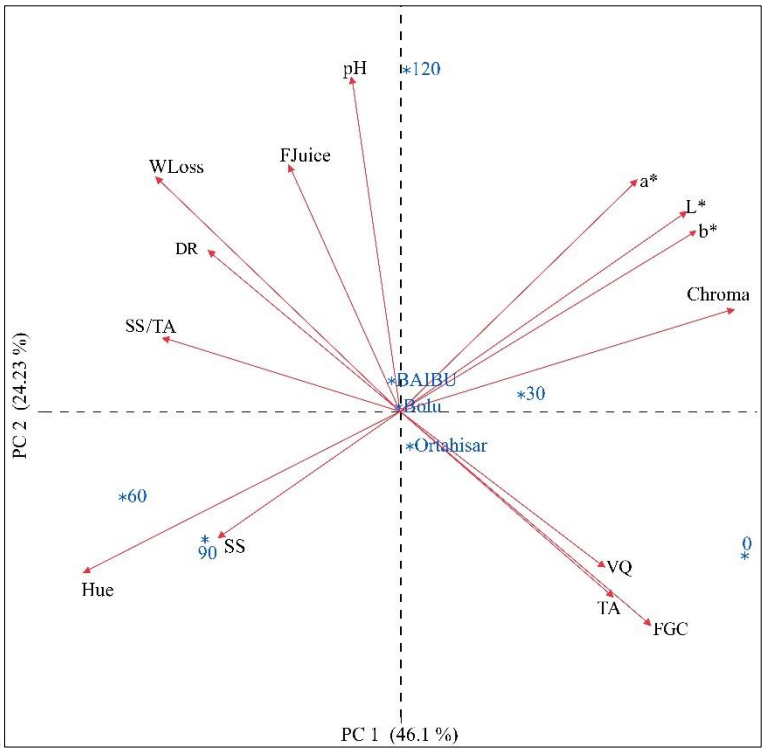


Figure 1. Correlations between measured parameters of Kutdiken lemon in different storages at postharvest.
Şekil 1. Kutdiken limonunun hasat sonrası farklı depolardaki ölçülen parametreler arasındaki korelasyonlar.

Principal Component Analysis (PCA): Similar to Figure 1, in the principal component analysis (Figure 2), some relationships are more clearly observed. PC1 and PC2 explained 65.84% the total relations. The height of acidity and the quantity of green-capped fruits (FGC), which measure consumer preference, are positively correlated with overall appearance (VQ). Overall appearance is inversely correlated with acidity and FGC, as well as with weight loss, fruit juice quantity, rotten fruit quantity, and SS/TA ratio. The L a b chroma values are inversely correlated with dry matter content and inversely correlated with the duration spent in storage. The duration spent in storage is positively correlated with dry matter content. Although

volcanic storage has good properties in the same direction, all storage facilities are at the center of the parameters measured with small differences. There doesn't seem to be a significant difference between valley storages and volcanic storages.

a)



b)

Number	Eigenvalue	Percent	Cum	Prob>ChiSq
1	5.21	40.07	40.07	<.0001
2	3.35	25.77	65.84	<.0001
3	1.62	12.47	78.31	<.0001
4	0.93	7.12	85.43	.0001
5	0.69	5.33	90.76	.0001
6	0.53	4.09	94.85	.0001
7	0.28	2.14	96.99	.0001
8	0.16	1.25	98.24	.0001
9	0.11	0.87	99.11	.0001
10	0.11	0.83	99.94	<.0001
11	0.01	0.05	99.99	<.0001
12	0.00	0.01	100.00	<.0001
13	0.00	0.00	100.00	*

Figure 2. PCA Analysis (a) and eigenvalues (b) of Kutdiken lemon data from different storages and days.
Şekil 2. Farklı depolar ve günlerde alınan Kutdiken limonu verilerinin PCA Analizi (a) ve eigenvalue değerleri (b).

According to Örüng et al., (2016), underground natural cold storage facilities provide significant advantages in the storage of agricultural products, especially in areas predominantly composed of tuff, such as the Cappadocia region. These facilities are particularly concentrated in the towns of Kavak and Ortahisar (Boyraz and Zeren, 2012). The temperature in underground storage facilities is more stable compared to aboveground storage facilities due to the natural rock structure. Throughout the year, even during dry summers or harsh winters, the temperature remains between 8-10°C (Seedoga, 2022).

Reviewing the literature, weight loss in *Citrus* fruits stored in storage facilities increases over time (Karaşahin et al., 2014; Nural, 2019; Özdemir, 2008; Özkaya, 2007; Özdemir et al., 2008). The findings of the study align with existing research in the literature, as the nature of respiration in fruits makes this phenomenon predictable.

Most of the deterioration in *Citrus* fruits occurs in the form of spots and depressions on the peel and stem end (Özdemir, 1999; Strano et al., 2022). In this study, physiological deterioration increased as storage time prolonged, consistent with literature. Factors such as deviations from optimum temperature are important in increasing decay (Borazan, 2019; Canan, 2004; Zan, 2018). As storage time increases and factors such as temperature, humidity fluctuates in the storage facility, and physiological and fungal decay increases (Özdemir et al., 2016; Strano et al., 2022). The construction of isothermal doors in storage facilities, the use of heater rods connected to thermostats, and the implementation of ventilation systems would be appropriate for maintaining temperature and humidity levels (Canan, 2004).

Another storage criterion, the quantity of green-capped fruits (FGC), being high implies a reduction in losses. A significant proportion of the decay in *Citrus* fruits occurs after the capsule turns brown. During storage, all fruits for each application and each replicate were examined, and green-capped, brown, dried, and uncapped fruits were identified, and the rates of green-capped fruits were determined. As the storage

time of *Citrus* fruits prolongs, the capsule turns brown and black and falls off. The fall of the fruit capsule creates an entry environment for the fungal disease Alternaria citri (Strano et al., 2017). Our findings are similar to previous studies on lemons, oranges, and mandarins (Ağar and Kaşka, 1992, 1993; Azak, 1994; Canan, 2004; Didin et al., 2018; Erkan, 1997; Gül, 1996; Karaşahin et al., 2014; Özdemir et al., 2005, 2007, 2008, 2016, 2019; Topçu, 2020; Uzun, 2019; Zan, 2018).

According to Bartholomew and Sinclair (1951), there are increases in fruit juice content along with the storage time (Akpınar, 1990), and these increases are not related to the fruit absorbing moisture from the environment, but rather to the loss of moisture from the fruit peel due to physical and chemical processes. Increases in fruit juice content originate from the structure of the fruit peel and are closely related to water losses (Özdemir et al., 2005). The increase in free water, which is generally observed during the ripening process of the fruit, is thought to result from the increase in water volume due to soluble substances formed as a result of the breakdown of large molecules through respiration. In our experiment, increases in fruit juice content were observed along with the storage time. Similar results to ours were obtained in a study conducted by Canan (2004) on 'Kütdiken' lemon variety fruits stored in natural cooling storage and cold storage.

The TA (titratable acidity) levels of the fruits stored in lemons decreased as the storage time increased. Previous studies on the storage of *Citrus* fruits show similarities (Akpınar, 1990; Canan, 2004; Erkan, 1997; Özdemir, 1999). Anything that slows down metabolism, reduces respiration (low temperature, low oxygen, high carbon dioxide) also reduces acid loss (Karaçalı, 2009).

In the study by Canan (2004), the average maturity index ratio observed in fruit samples was initially 1.37, and it increased continuously as the storage time extended, with the highest increase seen at the 6th month (1.22). When reviewing the literature, it is observed that as the storage time increases, the maturity index also increases in *Citrus* fruits, which is consistent with this study (Borazan, 2019; Canan, 2004; Uzun, 2019).

Bolu province's annual average temperature of 10.5°C is just one aspect of its geographic situation; another important aspect is its geographical features. The consequences of its geographic features make it significant for natural cold storage. Geographically, one of the most important aspects is that Bolu plain is surrounded by high mountains like a deep and wide-mouthed water basin, and the city is located right in the center of this basin. As a result, even the slightest air movement in the vicinity causes the wind to rise as it hits these mountains, constantly forming clouds over the city. Especially due to the humid air currents coming from the Black Sea, the city center remains shaded for a significant part of the day throughout the year. Secondly, since the city center is settled at the bottom of a valley, the sun rises late and sets early. Thirdly, Bolu plain, nestled amidst mountains ranging from 1400 to 1800 meters in height, is a vast frost basin with the lowest point being 750 meters. Moist clouds over the city dissipate with the disappearance of the evening sunlight, condensing heavily on the cooled mountain surfaces, filling the Bolu plain through the Abant-Bolu Mountain, Mudurnu, and Gerede valleys until the first morning sun rises. This cold air mass reaches an altitude of about 200 meters over the plain. Throughout the night, the cold air mass covering the plain from three directions empties out only through the Mengen valley towards the Black Sea via one route, reaching its discharge point around noon at 12:00 PM. Consequently, the weather is cold and foggy for half of the day.

CONCLUSION

This study demonstrated that Kütdiken lemons can be stored in natural valley storage in Bolu, achieving comparable results to those in Ortahisar volcanic warehouse and thermomechanical storage at BAIBU, regarding weight loss, decay, and fruit quality parameters. Bolu's climatic conditions, combined with logistical advantages for markets like Istanbul and Ankara, position it as a viable alternative for lemon storage. Further research and support for establishing natural storage facilities in Bolu are recommended to enhance storage capacity and competitive pricing, potentially transforming Bolu into a significant food storage hub by integrating modern technologies with its natural cold air resource.

CONFLICT OF INTEREST

The author(s) hereby declare that there are no conflicts of interest related to this study. All financial and personal relationships that could influence the research have been disclosed, ensuring the integrity and transparency of the findings.

DECLARATION OF AUTHOR CONTRIBUTION

The authors declare that there are no conflicts of interest related to this study. Each author has made significant contributions to the research and preparation of the manuscript as detailed below, ensuring that all aspects of the work are accurately represented.

YY: Conducted the experiment, performed the laboratory analyses, collected the data, and wrote the thesis.

IC: Planned the experimental design, analyzed the raw data, conceptualized the study, wrote the manuscript, and followed up on the publication process.

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