

Comparison of Morphometric Traits of Pecan Cultivars

Ferhad MURADOĞLU¹, Sibel AKKUŞ BİNİCİ², Gökhan AKKUŞ³, İbrahim BAŞAK⁴

¹Abant İzzet Baysal University Faculty of Agriculture, Department of Horticulture, Bolu, ^{2,3}GAP Agricultural Research Institute, Şanhurfa,

⁴Agriculture and Rural Development Agency, Van Provincial Coordination Unit, Van/Türkiye

¹<https://orcid.org/0000-0001-6595-7100>, ²<https://orcid.org/0000-0002-5147-4447>, ³<https://orcid.org/0000-0003-0675-755X>

⁴<https://orcid.org/0000-0002-5160-3229>

✉: muradogluf@ibu.edu.tr.

ABSTRACT

Pecan is a major horticultural nut tree that originated in North America and, in Turkey, it is generally cultivated in the Aegean and Mediterranean regions. In this study, morphometric traits of twenty-one cultivars grown under equal ecological conditions in the Southeastern region of Turkey were determined. In addition, a multivariate analysis was performed on morphometric traits for determining suitable cultivars that show the best performance in these ecological conditions. The nut weight ranged from 3.66 g for 'Cherokee' to 10.35 g for the 'Shoshoni' cultivar. The 'Choctaw' had the highest kernel weight and kernel ratio ranging from 5.63 g to 58.60%. While the 'Cherokee' had the lowest ranging from 0.91 g to 22.84 g, respectively. A significant positive correlation between nut weight and kernel ratio was determined. The kernel weight was also highly correlated with nut weight and height. The use of clustering analysis according to Ward's method allowed the establishment of relationships between pecan cultivars by separating them into four main clusters. Also, these results were supported by principal component analysis, and 'Big Z' and 'Ideal' cultivars were determined to be the closest cultivars. Results showed that there are quantitative differences regarding the genetic property of pecan cultivars and more than half of the examined cultivars showed a good performance in terms of nut quality criteria that are crucial in marketing. Furthermore, the multivariate analysis was effective in the differentiation of pecan cultivars and it has been evaluated that it can be used successfully in future studies.

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Pikan Çeşitlerinin Morfometrik Özellikler Bakımından Karşılaştırılması

ÖZET

Pikan, aslen Kuzey Amerika orjinli olan ve Türkiye'de genellikle Ege ve Akdeniz bölgelerinde yetiştirilen önemli bir sert kabuklu meyve türüdür. Çalışmada, Türkiye'nin Güneydoğu bölgesinden aynı ekolojik koşullar altında yetiştirilen yirmi bir pikan çeşidinin morfometrik özellikleri belirlenmiştir. Ayrıca, bu ekolojik koşullarda en uygun çeşitlerin belirlenmesi için morfometrik özellikler üzerine çok değişkenli istatistiksel analiz uygulanmıştır. Çeşitlerin meyve ağırlığı 3.66 g 'Cherokee' ile 10.35 g 'Shoshoni' arasında değişmiştir. En yüksek iç ağırlığı ve iç oranı 'Choctaw' çeşidinde (5.63 g ve %58.60) en düşük ise "Cherokee" çeşidinde (0.91 g ile 22.84 %) belirlenmiştir. Meyve ağırlığı ile iç oranı arasında anlamlı pozitif bir ilişki bulunmuştur. Ayrıca, iç ağırlığının meyve ağırlığı ve yüksekliği ile yüksek önemli ilişkili olduğu belirlenmiştir. Ward yöntemine göre yapılan kümeleme analizi, pikan çeşitleri arasında ilişkilerin kurulmasına izin vermiş ve çeşitleri dört ana kümeye ayırmıştır. Elde edilen sonuçlar temel bileşen analizi ile desteklenmiş ve çeşitlerden en yakın ilişkisi 'Big Z' ile 'Ideal' arasında belirlenmiştir. Sonuçlar pikan çeşitlerinin genetik özellikleri ile ilgili niceliksel farklılıkların olduğu ve incelenen çeşitlerin yarısından fazlasının

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pazar tarafından arzu edilen meyve kalitesi açısından iyi bir performans sergilediğini göstermiştir. Ayrıca çok değişkenli analiz pikan çeşitlerinin ayırımında oldukça etkili olmuş ve ileriki çalışmalarda başarıyla kullanılabilceği değerlendirilmiştir

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INTRODUCTION

Pecan is a hard-shelled valuable fruit tree species that have a high economic value nut belonging to the *Juglandaceae* family, which also includes other tree and *Carya* varieties (Rosengarten, 1984). The pecan is a deciduous tree native to the North American continent, especially the USA and Mexico. Today, the USA and Mexico are the world's largest commercial pecan producers with about 75%, and 20% of world production, respectively (Hadigeorgalis et al., 2005; Venkatachalam et al., 2007; Thompson and Conner, 2012). Pecan is a popular fruit with a pleasant taste, and medicinal and nutritive properties, so the demand for it is increasing worldwide. Plantations are being established in many countries outside of North America such as; Australia (Wakeling et al., 2000), Argentina (Giuffré et al., 2011), and China (Zhang et al., 2015). The other important pecan-producing countries are Israel, South Africa, and Turkey).

Pecan is a healthy food that has always found an important place in food production and human nutrition the pecan is consumed fresh or in various food products such as pies and cakes as well as in salads and topping of desserts (Thompson and Conner, 2012). In addition to being edible, pecan oil is also used in cosmetics, medicine, paints, and essential oil production (Prasad, 1993; Duke, 2001). Pecan consists of 9-18% protein, which is lower compared to other nuts, and it consists of 14% carbohydrate depending on cultivars. Pecans are a fine source of dietary fiber, and they are also rich in terms of minerals including manganese, phosphorus, magnesium, zinc, iron, and naturally low in sodium (Prasad, 1993; Gebhardt and Thomas, 2002; USDA, 2004; Curiel-Maciél et al., 2021). Furthermore, pecans have high oil contents, about 65-70%, depending on cultivars, and the oil profile is mostly comprised of monounsaturated (commonly oleic acid) and polyunsaturated fatty acids (linoleic acid). Pecan consists of high antioxidants including vitamin B complex, beta-carotene, ellagic acid, lutein, and vitamin E (Rudrappa, 2016; Binici Akkuş et al., 2020; Özdemir et al., 2021; Curiel-Maciél et al., 2012).

Research shows that pecan has major beneficial effects on cholesterol and triglyceride levels. Moreover, regular pecan consumption affects the

increase of HDL cholesterol and the reduction of triglycerides and apolipoprotein B levels. Pecan is considered cholesterol-free heart-healthy friendly food and can improve human blood fat profiles and low-density lipoprotein levels because of the high monounsaturated fatty acid contents (Ros, 2010).

The pecan was introduced from North America to Turkey and has been generally spread in Antalya and İzmir regions that have subtropical and temperate climates. Therefore, pecan nut production has been intensive throughout the coastal regions of the Mediterranean and Aegean in Turkey. Some important cultivars were planted in the Southeastern Anatolia Agricultural Research Institute collection orchard in Sanliurfa province in 1992 to determine the performance of pecan cultivars in the South Eastern Anatolia region. The pecan is commercially cultivated in temperate, tropical, and subtropical regions of the world. Since pecan growing is limited in Turkey due to the restriction of climatic conditions, which is more suitable for walnut (*Juglans regia*) growing, there is no data available on pecan production in Turkey.

There are studies on the chemical compositions of pecan cultivars. But, to the best of our knowledge, there have not been studies on the morphometric properties of pecan cultivars grown under equal ecological conditions. With the present study, we aimed to compare the morphometric traits of twenty-one pecan cultivars that were grown in the same cultural practices and climatic conditions by performing multivariate analysis on the main nut characteristics preferred by the market. The results of this study will make a positive contribution to the producers in the region regarding the cultivation of pecan.

MATERIAL and METHOD

Plant material

In the study, morphometric traits of 21 pecan cultivars (Big Z, Harris Super, Hastings, Ideal, Kiowa, Mahan, MahanxStuart, Mohawk, Pawnee, Royal, Schley, Shawnee, Shoshoni, Texhan, Western, and Wichita) from Southeastern Anatolia Agricultural Research Institute collection orchard at 477 m altitude in Şanlıurfa province were evaluated

through two sequential years. The trees were twenty-three years old and planted out 12x12 m within and between row spacings. Plants were regularly fertigated and weed, pest, and disease control were performed properly. No nutritional deficiency was observed on trees and all cultural practices were done properly during the study.

Method

Twenty nuts from each cultivar were measured over two years. Morphometric characters including nut width (NW), nut length (NL), nut height (NH), and shell thickness (SC) were measured using a caliper with an accuracy of 0.1 mm. Nut weight (NWT) and kernel weight (KWT) were measured with an electronic scale with a 0.01 g precision. Frequency distribution of used characters such as shell color, kernel color, kernel ratio, shell thickness, and harvest date were determined according to UPOV criteria, Pecan Descriptors Bulletin (available at: https://www.upov.int/meetings/en/doc.details.jsp?meeting_id=35045&doc_id=297728).

Ecological data of research area

Climatic information, monthly maximum temperature (°C), monthly average temperature (°C), monthly precipitation (kg/m²), monthly average humidity (%), and monthly average wind speed (m/s) were received from the Turkish State Meteorological Service (MGM) and shown from 1st January to 31st December for two consecutive years (2015 and 2016).

Statistical Analysis

Descriptive statistics in the examined characters as the minimum (min), maximum (max), mean, standard error (SE), Duncan's multiple range test, and coefficient of variations (CV%) were determined by using the statistical package program of SPSS. One-way ANOVA and Duncan test were used to compare the cultivars in terms of characteristics and the statistical significance level was considered as 5% in the calculations. Moreover, the relationship among characteristics was determined by Pearson's correlation analysis utilized by the R Studio software and the 'corrplot' package (Wei et al., 2017). The principal component analysis (PCA) was conducted to clarify the relationships of features with each other being utilized by R Studio software and the package of 'ggplot2' (Wickham, 2016). Clustering analysis (CA) was utilized to create a dendrogram showing the hierarchical distribution of cultivars in terms of studied characteristics.

RESULTS and DISCUSSION

Ecological data of research area

The monthly average temperature showed a regular

rise from January to July and a slight decrease was observed in August. The highest monthly temperature was monitored in July at 44.1 °C. The monthly average relative humidity and monthly precipitation occurred mostly in the winter months, and a decline was observed in June and July. Also, parallelism was determined between monthly precipitation and relative humidity. The monthly average wind speed was slightly higher in the spring months (March, April, May, and June) than in the others. While no significant difference was observed in temperature data between years, the precipitation amount and distribution were dissimilar compared to the previous year (Figure 1).

Fruit yield and quality are closely related to environmental conditions. Very low and high temperatures, light quantity and quality, soil temperature, altitude, relative humidity, and wind speed have detrimental effects on fruit trees. Unsuitable environmental conditions cause problems in flowering and fruit sets. The areas with below 55% humidity and up to 150-200m altitudes, which have long hot summers, short and not very hard winters, and rare early or late frosts, are suitable for pecan growing (Dolgun et al., 2020). In the research area, summers are hot and dry, winters are warm and rainy, and humidity is lower than 55% during the vegetation period that is suitable for pecan growing. On the other hand, the altitude is a little high, which may cause appearances of late and early frosts.

Morphometric traits of cultivars

A high variation and significant ($P < 0.05$) differences were observed between the morphometric traits of cultivars. These differences were due to genetics because cultural practices and ecological conditions were equal for all cultivars. The morphometric traits that are important for consumers were determined. Shell color, nut dimensions (width, length, and height), nut weight, kernel weight, and color traits in twenty-one pecan cultivars are presented in Tables 1 and 2. Shell color and kernel weight showed the highest CVs (43.27 and 40.48%, respectively) while nut length (10.68%) and nut width (12.92%) had the lowest CVs. NWT, KWT, KC, KR, ST, and HD had higher than 20.00% CVs (Table 1). The NW, NL, and NH had low CVs indicating that these may be considered more stable traits. Similar CVs in terms of morphometric traits were observed on other nuts such as walnut (Khadivi et al., 2015; Başak et al., 2022), chestnuts (Corona et al., 2021), hazelnut (Mohammad et al., 2014), and other fruits such as hawthorn (Muradoglu et al., 2021).

Nut size is more important for marketing that prefers large nuts for the succulent quality kernel. Generally, nut weight above 9.5 g is desirable for pecan (Wells and Corner, 2012), while smaller nuts than 8.0 g are

not preferred by the market. In the investigated cultivars, nut traits are shown in Table 2. The nut width varied between 19.43 and 27.30 mm. the largest nut width was determined in the ‘Wichita’ cultivar, while the ‘Shoshoni’ cultivar was the smallest one. The largest nut length was determined

50.84 mm by the ‘Mahan’ cultivar, and the smallest one 35.86 mm by the ‘Cape Fear’ cultivar. The nut height varied from 22.98 to 29.45 mm, ‘Choctaw’ cultivar was found the largest in section, and the smallest section was found on the ‘Cherokee’ cultivar.

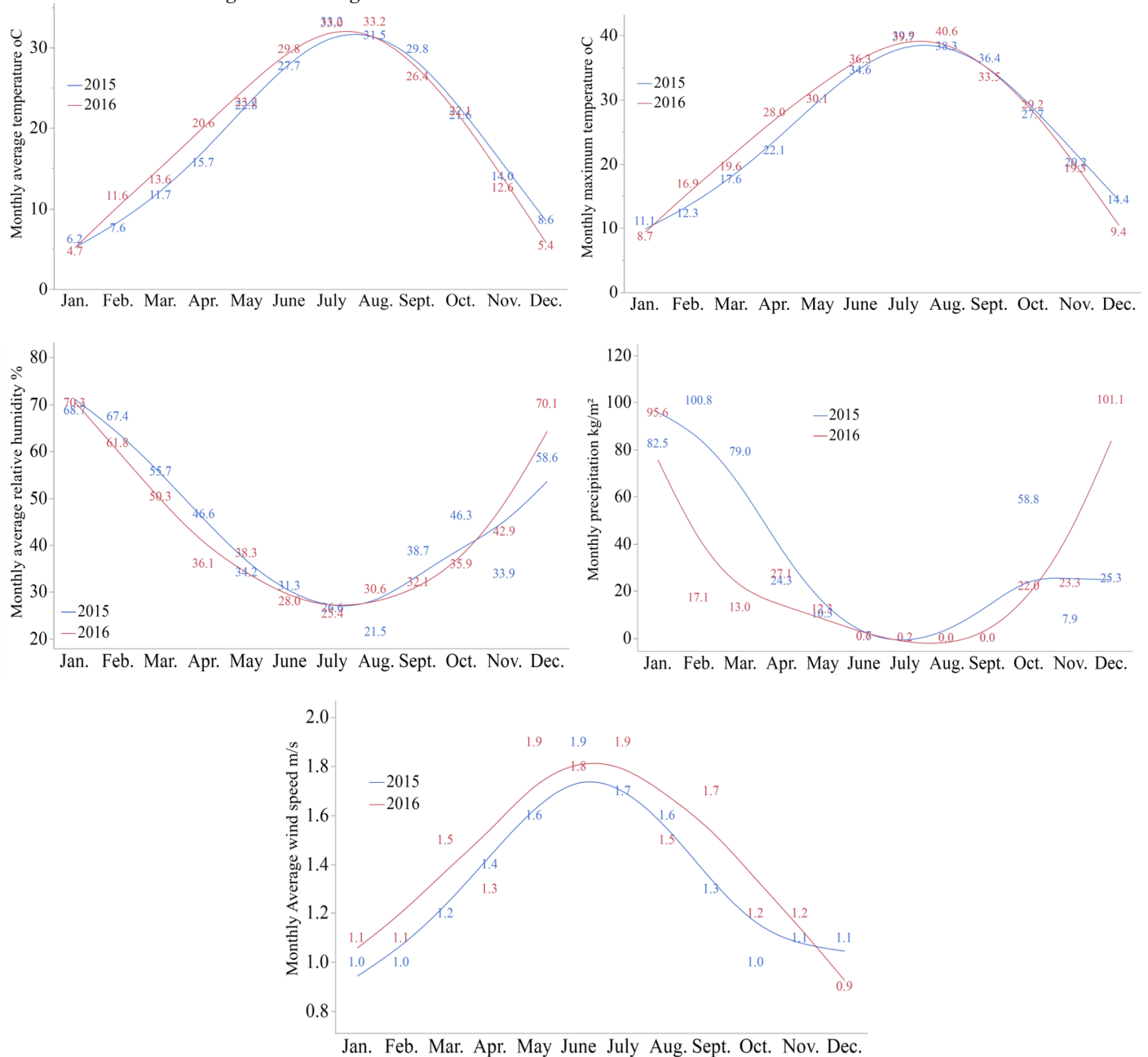


Figure 1. Meteorological data belonging to the research location

Resim 1. Araştırma alanına ait iklim verileri

The nut weight was between 3.66 and 10.35 g. The largest nut weight was measured in the ‘Shoshoni’ cultivar, while the ‘Cherokee’ cultivar was the smallest one. Seven cultivars were show good performance with 9 g and above kernel weight which was a preferable limit for markets. In addition, kernel weight was defined as 8 g and above in three cultivars, while ten cultivars were smaller than 8 g

(Table 2). The nut weight and kernel ratio varied between 0.91 and 58.60 g, between 5.63 and 22.84% respectively, and for both the highest rate was calculated for ‘Choctaw’ while the lowest rate was for ‘Cherokee’. Shell thickness varied from 0.61 mm ‘Mahan’ to 1.20 mm ‘Shoshoni’. Kernel quality is relative to kernel ratio and desirable high kernel ratio of 50% and higher by customers. The ‘Choctaw’ and

'Western' cultivars yielded the highest kernel ratio, 58.60%, and 58.45%, respectively. However, the lowest kernel ratio (22.84%) was determined in 'Cherokee'. The high relationship between kernel weight and kernel ratio is a well-known phenomenon

in nut crops (Khadivi et al., 2019). The regression plot illustrated in Figure 2 proves a significant positive association ($r=0.80$, $P<0.0001$) between kernel weight and kernel ratio was observed a significant positive association.

Table 1. Illustrative statistics for morphometric characters in the pecan cultivars.

Çizelge 1. Pikan çeşitlerinde morfolojik karakterlerin istatistiksel tanımlanması.

Traits	Abbrev	Unit/code	Minimum	Maximum	Mean	SE	CV
Nut width	NW	mm	15.93	30.11	23.20	0.15	12.92
Nut length	NL	mm	25.51	54.42	40.77	0.21	10.68
Nut height	NH	mm	18.44	36.29	26.71	0.18	13.79
Nut weight	NWT	g	2.24	13.72	8.11	0.12	29.26
Kernel weight	KWT	g	0.35	8.51	4.17	0.08	40.48
Kernel color	KC	Code	1.00	3.00	2.10	0.02	20.35
Kernel ratio	KR	%	9.77	82.28	49.57	0.55	22.53
Shell color	SC	Code	1.00	4.00	1.95	0.04	43.27
Shell thickness	ST	mm	0.41	1.67	1.00	0.01	24.85
Harvest date	HD	Date	1.00	4.00	3.10	0.04	28.07

Frequencies (%)

Frekanslar (%)

Kernel color	KC	Code	Light (4.76)	Medium (80.95)	Dark (14.29)	
Shell color	SC	Code	Extra light (28.57)	Light (57.14)	Medium (4.76)	Dark (9.52)
Kernel ratio	KR	%	Small (47.61)	Medium (14.28)	Large (38.09)	
Shell thickness	ST	mm	Thin (19.04)	Medium (47.61)	Thick (33.33)	
Harvest date	HT	Date	Very early (9.52)	Early (4.76)	Medium (52.34)	Late (33.33)

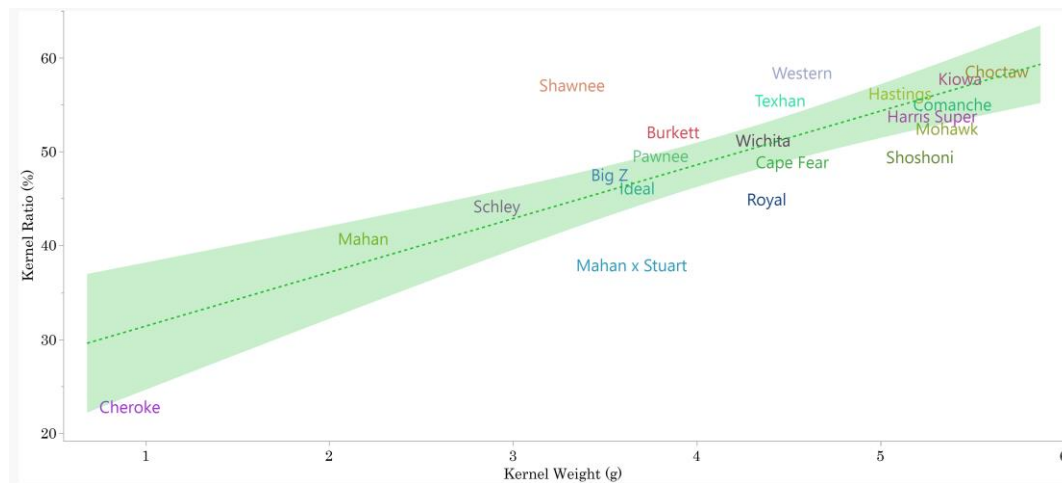


Figure 2. Regression plot for kernel ratio and kernel weight in pecan cultivars.

Resim 2. Pikan çeşitlerinde iç oranı ve iç ağırlığına ait regresyon grafiği.

Nut and kernel color are major parameters for pecan cultivars and desirable kernel color is 'light' for marketing and breeding value. In addition, previous works showed that the oxidation of polyphenols and fatty acids contents is relatively within the color sensory of walnut (Muradoglu and Balta, 2010; Fuentealba et al., 2017). A total of 6 cultivars (28.57%) had 'extra light', 12 cultivars had 'light', 1 cultivar 'medium', and only two cultivars had 'dark' skin color. The kernel color of 1 cultivar (4.76%) was 'light', 17 (80.95%) was 'medium', and 3 (14.29%) was 'dark'.

The cultivars were suitable for marketing in terms of

the skin at a rate of 84.17% rate and kernel color at 38.09%. (Tables 1 and 2). The earliest harvested cultivars were 'Royal' and 'Wichita' followed by another early cultivar 'Shoshoni'. Seven cultivars were determined late in terms of harvest time. The average harvest date for very early in this region was 10 October and for the late cultivars was 15 November. Similar results were reported by Badyal and Upadhyay (2004) who reported nut length, width, weight, kernel weight, and kernel percentage varied from 31.6 to 54.0 mm, from 23.2 to 34.0 mm, from 3.59 to 5.71 g, from 2.10 to 3.90 g, from 8.30 to 55.2%, respectively. In another study conducted on 5

pecan cultivars, nut traits were investigated and reported as 5.42-10.84 g for nut weight, 34.51-51.83 mm for nut length, 21.99-26.18 mm for nut width, 23.20-25.40 mm for nut height, 2.42-6.10 g for kernel weight, and 0.58-1.10 mm for shell thickness. (Binici Akkuş et al., 2020). Similarly, nut weight and kernel ratio of pecan cultivars were reported as 3.98-8.40 g and 43.55-59.28% by Reid and Hunt (2000) and 0.8-

6.9 g and 41.1-62.3% by Poletto et al., 2020.

Studied cultivars showed major diversity because of genetic factors. Also, morphometric traits of studied pecan cultivars were in close relationship with previous findings, but minor differences related to cultivars factors, edaphoclimatic conditions, different locations, maturity stages, and cultural practices have existed.

Table 2: Some nut traits of investigated Pecan cultivars.

Çizelge 2. İncelenen pikan çeşitlerinin bazı meyve özellikleri.

Cultivars	NW (mm)	NL (mm)	NH (mm)	NWT (g)	KWT (g)	ST (mm)	KR (%)	SC	KC	HD
Big Z	23.29±0.28 ^{fg}	40.93±0.41 ^{eh}	26.62±0.73 ^{bc}	7.38±0.20 ^{fg}	3.52±0.12 ^{hj}	1.03±0.02 ^{bc}	47.58±0.63 ^{ch}	L**	M	Late
Burkett	19.62±0.18 ^j	44.21±0.61 ^c	25.83±1.01 ^{bc}	7.32±0.26 ^{fg}	3.87±0.25 ^{fi}	1.02±0.06 ^{bf}	52.12±1.94 ^{cf}	EL	M	Medium
Cape Fear	25.41±0.23 ^{bd}	35.86±0.73 ^{lm}	26.03±0.52 ^{bc}	9.25±0.20 ^{ab}	4.52±0.12 ^{cg}	1.19±0.05 ^a	48.94±0.90 ^{eh}	L	M	Late
Cherokee	21.59±0.31 ^{hi}	37.16±0.47 ^{kl}	22.98±0.36 ^f	3.66±0.23 ^j	0.91±0.161 ^l	1.07±0.04 ^{ad}	22.84±2.48 ^k	EL	D	Late
Choctaw	26.23±0.21 ^{ab}	41.58±0.48 ^{df}	29.45±0.61 ^a	9.51±0.48 ^{ab}	5.63±0.35 ^a	1.02±0.03 ^{bf}	58.60±0.86 ^a	L	M	Medium
Comanche	26.56±0.40 ^{ab}	39.36±0.43 ^{hj}	29.43±0.55 ^b	9.76±0.39 ^{ab}	5.39±0.24 ^{ac}	1.15±0.05 ^{ac}	55.06±0.74 ^{ad}	M	M	Medium
Harris Super	21.21±0.68 ^{hi}	39.55±1.16 ^{fi}	23.31±0.40 ^f	9.71±0.34 ^{ab}	5.28±0.26 ^{ad}	0.88±0.02 ^{fg}	53.82±1.54 ^{ae}	D	M	Medium
Hastings	24.92±0.45 ^{ce}	39.72±0.41 ^{fi}	28.52±0.65 ^{ab}	8.95±0.34 ^{bd}	5.11±0.28 ^{ae}	0.90±0.03 ^{eg}	56.23±1.35 ^{ad}	L	M	Medium
Ideal	22.11±0.23 ^{gh}	40.78±0.60 ^{ei}	27.27±0.89 ^{ad}	7.98±0.29 ^{cf}	3.67±0.15 ^{fi}	1.16±0.03 ^{ab}	46.15±1.26 ^{ch}	L	M	Late
Kiowa	22.01±0.75 ^h	41.36±0.75 ^{de}	27.71±1.05 ^{ac}	9.14±0.51 ^{ac}	5.43±0.42 ^{ab}	0.95±0.05 ^{dg}	57.81±1.84 ^{ab}	L	M	Medium
Mahan	22.48±0.27 ^{gh}	50.84±0.51 ^a	26.92±0.83 ^{bc}	5.15±0.24 ^l	2.19±0.21 ^k	0.61±0.03 ^h	40.77±2.44 ^j	L	M	Late
MahanxStuart	23.80±0.71 ^{ef}	43.25±0.76 ^{cd}	28.20±0.46 ^{ac}	8.64±0.78 ^{bc}	3.65±0.50 ^{gi}	1.15±0.05 ^{ab}	37.94±2.92 ^j	L	D	Late
Mohawk	26.01±0.35 ^{bc}	37.94±0.36 ^{jk}	27.76±0.61 ^{ac}	10.18±0.30 ^a	5.36±0.19 ^{ac}	0.92±0.02 ^{eg}	52.49±0.62 ^{bf}	D	L	Late
Pawnee	25.31±0.30 ^{bd}	41.99±0.63 ^{de}	26.93±1.11 ^{bc}	7.57±0.34 ^{eg}	3.80±0.28 ^{fi}	0.94±0.05 ^{dg}	49.59±2.62 ^{ch}	L	M	Medium
Royal	24.58±0.28 ^{de}	38.92±0.46 ^{ik}	27.89±0.88 ^{ac}	9.70±0.20 ^{ab}	4.38±0.16 ^{ch}	1.11±0.05 ^{ac}	44.95±1.17 ^{hi}	EL	M	Very early
Schley	24.09±0.24 ^{ef}	34.88±0.28 ^m	24.64±0.42 ^{ef}	6.44±0.32 ^{gh}	2.91±0.22 ^{jk}	0.99±0.06 ^{cf}	44.23±1.57 ^{hi}	L	M	Medium
Shawnee	19.44±0.25 ^j	38.96±0.52 ^{ik}	24.98±0.63 ^{df}	5.73±0.25 ^{hi}	3.32±0.21 ^{ji}	0.82±0.03 ^e	57.11±1.70 ^{ac}	EL	M	Medium
Shoshoni	27.30±0.37 ^a	38.23±0.72 ^{jk}	27.92±0.36 ^{ac}	10.35±0.46 ^a	5.22±0.34 ^{ae}	1.20±0.04 ^a	49.46±1.52 ^{sh}	L	M	Early
Texhan	20.48±0.16 ^{ij}	46.23±0.37 ^b	26.88±1.13 ^{bc}	7.94±0.28 ^{df}	4.45±0.25 ^{dg}	0.91±0.04 ^{eg}	55.49±1.84 ^{ad}	EL	M	Medium
Western	21.28±0.17 ^{hi}	42.35±0.47 ^{de}	25.15±0.92 ^{df}	7.81±0.22 ^{df}	4.57±0.16 ^{bc}	0.89±0.05 ^{eg}	58.45±1.55 ^a	E	M	Medium
Wichita	19.43±0.71 ^j	41.90±0.68 ^{de}	26.35±0.58 ^{bc}	8.07±0.61 ^{cf}	4.36±0.47 ^{eh}	1.00±0.06 ^{bf}	51.24±2.04 ^{de}	L	D	Very early
Average	23.20±0.14	40.76±0.21	26.70±0.17	8.11±0.11	4.17±0.08	1.00±0.01	49.56±0.54	SC	KC	HD

*Different letters in lines indicate significantly different values at $p \leq 0.05$. NW: nut width, NL: nut length, NH: nut height, NWT: nut weight, KWT: kernel weight, ST: shell thickness, KR: kernel ratio, SC: shell color, KC: kernel color, HD: harvest date. **L: light, EL: extra light, M: medium, D: dark.

The correlation and distribution of the morphometric traits were exhibited with the scatterplot matrix (Figure 3). Morphometric traits showed a highly significant and highly positive correlation ($P < 0.0001$) between NH and NW, NH, and NL ($P < 0.001$). KWT had highly significant and positive correlations ($P < 0.0001$) with NH, NWT, and KR. Nut weight exhibited a highly significant and positive correlation with Nut height, nut weight, as well as KR and NW ($P < 0.01$) exhibited significant positive correlations. Furthermore, significant negative correlations were identified between ST and NL ($P < 0.001$) and KR and NW ($P < 0.01$). Previously, Poggetti et al. (2017) reported negative relationships between nut weight and kernel ratio and nut ratio and shell thickness, while there were positive correlations with kernel weight, shell thickness, and kernel skin color in walnut. Similar results were reported by Guler et al. (2020) in rosehip observing positive relationships between fruit width, fruit weight, and fruit shape index.

The principal component analysis (PCA) separated the pecan cultivars according to their morphometric traits. Nine principal components were significant

($P < 0.001$), and four components explained 75.44% of the total variance (Figure 4). The first component (PC1) constituted 32.5 % of the total variance and was positively correlated with nut width and weight, kernel weight, and ratio while negatively correlated to kernel color. The second component (PC2) constituted 16.5 % of the total variance and was mostly defined by nut height, shell thickness, and negative kernel ratio. The remaining components also contained other variables and explained less variability (24.5 % of total variance). PCA is performed to identify the main factors and parameters that are discriminant among studied traits (Khadivi et al., 2015). PCA was successfully conducted to determine diversity among different fruit species or genotypes such as walnut (Özcan et al., 2020; Başak et al., 2022), hawthorn (Muradoglu et al., 2021), and rosehip (Güler et al., 2021).

The couples of the highest similarities among the cultivars were identified by the Hierarchical cluster analysis and presented in Figure 5. The highest similarity was between 'Big Z' and 'Ideal', while the farthest distance was between 'Big Z' and 'Burkett'.

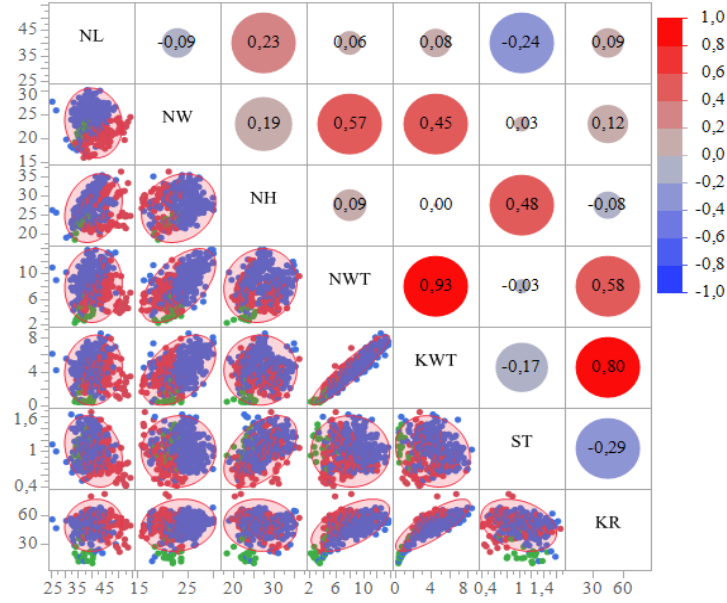


Figure 3. Scatterplot matrix demonstrating morphological traits pairwise. The color gradient (red to blue) and the size of the circles show the amount and significance of correlations.

Resim 3. Morfolojik özellikleri gösteren dağılım grafiği matrisi. Renk gradyanı (kırmızıdan maviye) ve dairelerin boyutu, korelasyonların miktarını ve önemini göstermektedir.

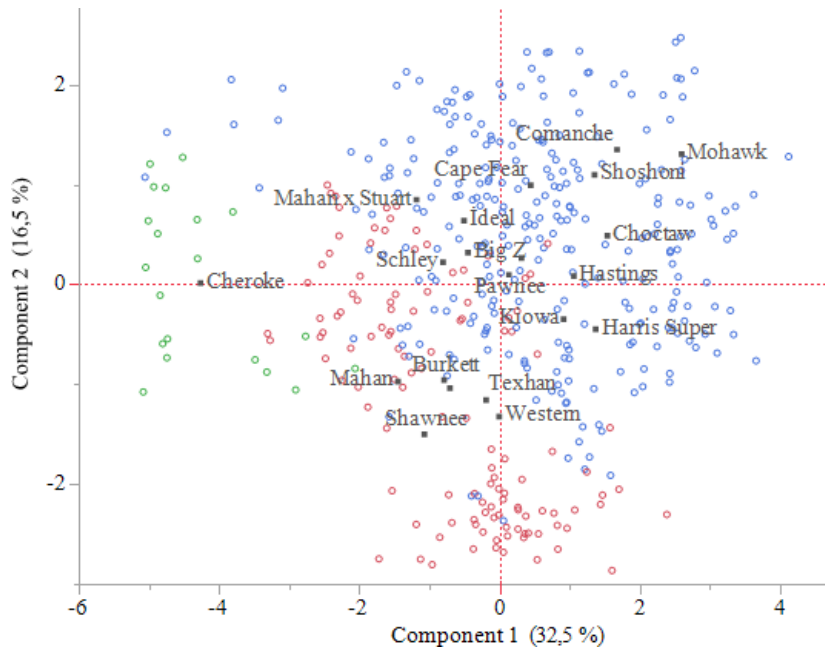


Figure 4. Distribution of pecan cultivars according to morphometric traits.

Resim 4. Pikan çeşitlerinin morfometrik özelliklerine göre dağılımı.

The cultivars were clustered into four main groups and the first group consisted of two subgroups with six cultivars. The first subgroup consisted of five cultivars 'Big Z', 'Ideal', 'Pawnee', 'Cape Fear', and 'Schley' while the second subgroup consisted of one cultivar, 'MahanxStuard'. The first cluster was characterized by low HD values. The second main group is comprised of eight cultivars in two subgroups. The first subgroup was containing 'Choctaw', 'Hasting', 'Kiowa', Comanche', Shoshoni', and 'Royal' cultivars. The second subgroup was

formed by 'Harris Super' and 'Mohawk' cultivars. The second cluster was mostly characterized by, SC, NW, NH, KWT, NWT, and KR. Cluster three included 'Burket', Texhan', Western', 'Wichita', and 'Mahan' cultivars characterized by NL. The 'Cherokee' cultivar formed the fourth group by itself demonstrating low values of KC and HD traits. The HC and the PCA showed a similarity in terms of grouping cultivars according to morphometric traits. correlation

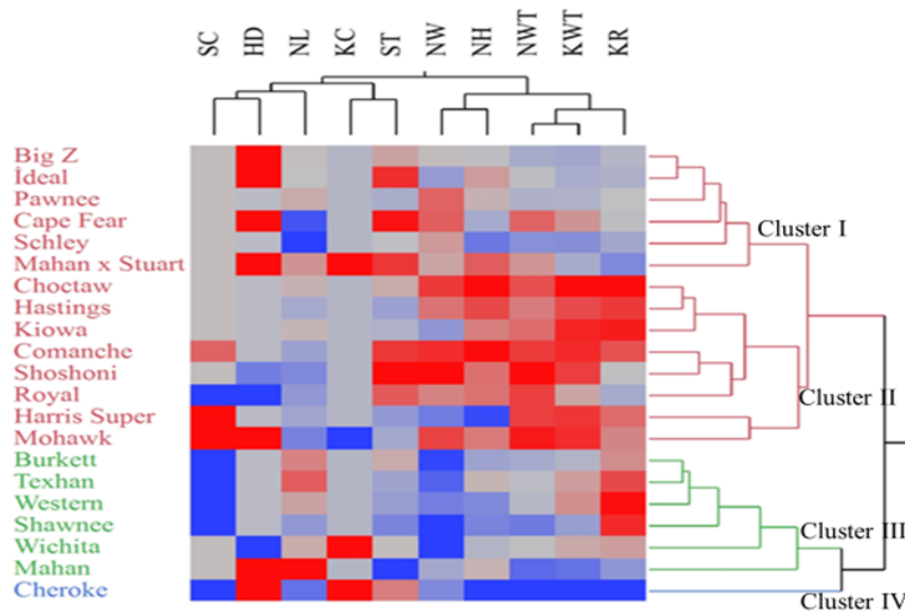


Figure 5. Hierarchical clustering and heatmap analysis based on the morphological characters studied for the twenty-one pecan cultivars. The highest and lowest morphological traits measurements belong to red and blue colors, respectively.

Şekil 5. Yirmi bir pıkan çeşidi için incelenen morfolojik karakterlere dayalı hiyerarşik kümeleme ve ısı haritası analizi. En yüksek ve en düşük morfolojik özellik ölçümleri sırasıyla kırmızı ve mavi renkle gösterilmiştir.

CONCLUSION

This study, which was carried out on 21 pecan cultivars in Şanlıurfa province in southeastern Anatolia, revealed great variability in morphometric traits. In the study, only morphometric traits that could be reasonably observed were monitored. Traits that are valuable for marketing and future breeding programs such as nut appearance, skin color, nut weight, kernel color, kernel weight, kernel ratio, and harvest date were examined by Multivariate analysis. In this study, 'Choctaw', 'Hasting', 'Kiowa', 'Comanche', 'Harris Super', 'Mohawk', 'Shoshoni', 'Western', and 'Texhan' cultivars showed ideal values of nut size and kernel quality that are desirable in marketing. Considering these quality criteria, these cultivars are suggestable for cultivation in this region.

The results will contribute to the cultivation of pecan both in Şanlıurfa and other provinces of the Southeastern Anatolia Region. Moreover, the results will encourage growers to establish new orchards in the region. In addition, variations among cultivars and relationships of morphometric traits that were revealed by multivariate analysis can be used in future breeding programs.

Statement of Conflict of Interest

The authors declare that they have contributed equally to the article.

Author's Contributions

The authors of the article declare that there is no conflict of interest between them.

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