KSÜ Tarım ve Doğa Derg 29 (2), 291-308, 2026
KSU J. Agric Nat 29 (2), 291-308, 2026
https://doi.org/10.18016/ksutarimdoga.vi.1674372

# Determination of Agro-Morphological Characteristics in Local Tomato (*Solanum lycopersicum* L.) Genotypes Collected from Central Anatolia Region

Alim AYDIN[1], Hakan BAŞAK[2], Ayşe Nur ŞAVKAN[3]✉, Ramazan GÜNGÖR[4]
[1,2,3]Department of Horticulture, Faculty of Agriculture, Kırşehir Ahi Evran University, Kırşehir, Türkiye, [4]Department of Plant and Animal Production, Vocational School of Technical Sciences, Kırşehir Ahi Evran University, Kırşehir, Türkiye
[1]https://orcid.org/0000-0002-9424-5556, [2]https://orcid.org/0000-0002-1128-4059 [3]https://orcid.org/0000-0002-0826-1243
[4]https://orcid.org/0000-0001-9834-1265
✉: ayse.cetin@ahievran.edu.tr

## ABSTRACT

In this study, 116 tomato genotypes collected from the Central Anatolia region were subjected to agro-morphological characterization and association analysis. For agro-morphological characterization, observations and measurements were carried out on 30 traits (18 qualitative and 12 quantitative) determined according to the criteria specified by UPOV and IPGRI. The 116 genotypes were evaluated in terms of morphological and quality traits, and the sources of variation were revealed through Principle Component Analysis (PCA), clustering, and correlation analyses. According to PCA results, the first two components, explaining 31.4% of the total variance, highlighted clear relationships between fruit size and structural traits (average fruit weight, fruit width, fruit length, and number of locules) and quality parameters (SSC, fruit and flesh colour, colour values, and fruit firmness). Cluster analysis based on the heat map grouped the genotypes into four main clusters: small and firm-fruited genotypes (Group 1), genotypes with vigorous plant growth and large fruits but low sugar content (Group 2), high-quality genotypes with intense colour, firmness, and high SSC representing the highest market value (Group 3), and genotypes with intense red colour but low firmness and susceptibility to blossom-end rot (Group 4). Correlation analyses revealed a clear trade-off between fruit yield and quality traits, indicating that larger and more locule-rich fruits may have lower dry matter content. Overall, the findings demonstrated that PCA and clustering analyses effectively distinguished the differences among tomato genotypes, and these results provide important contributions both to the selection of genotypes with high market value and to guiding breeding programs focusing on either yield or quality improvement.

**Horticulture**

**Research Article**

**Article History**
Received : 11.04.2025
Accepted : 07.09.2025

**Keywords**
Agromorphological characterization
Quality traits
Genetic variation
Cluster analysis

# İç Anadolu Bölgesinden Toplanan Yerel Domates (*Solanum lycopersicum* L.) Genotiplerinde Agro-Morfolojik Özelliklerin Belirlenmesi

## ÖZET

Bu çalışmada, İç Anadolu bölgesinden toplanmış 116 adet domates genotipinin, agromorfolojik karakterizasyonu ve ilişkilendirilmesi gerçekleştirilmiştir. Agro-Morfolojik karakterizasyon için UPOV ve IPGRI tarafından belirtilen kriterler dikkate alınarak belirlenen 30 adet özelliğe (18 adet nitel; 12 adet nicel) ait gözlem ve ölçümler yapılmıştır. Çalışmada 116 adet genotipi morfolojik ve kalite özellikleri bakımından değerlendirilmiş ve varyasyon kaynakları temel bileşen analizi (TBA), küme ve korelasyon analizleriyle ortaya konulmuştur. TBA sonuçlarına göre, toplam varyansın %31.4'ünü açıklayan ilk iki bileşen, meyve büyüklüğü ve yapısal özellikler (ortalama meyve ağırlığı, meyve eni, boyu ve lokul sayısı) ile kalite parametreleri (SÇKM, meyve ve et rengi, renk değerleri, meyve sertliği) arasında belirgin ilişkiler ortaya koymuştur. Isı haritasına dayalı küme analizinde genotipler dört ana grupta toplanmış; küçük ve sert meyveli genotipler (Grup 1), güçlü bitki gelişimi ve iri meyvelere sahip ancak düşük şeker içerikli genotipler (Grup 2), yüksek

**Bahçe Bitkileri**

**Araştırma Makalesi**

**Makale Tarihçesi**
Geliş Tarihi : 11.04.2025
Kabul Tarihi : 07.09.2025

**Anahtar Kelimeler**
Agromorfolojik karakterizasyon
Kalite özellikleri
Genetik varyasyon
Küme analizi

renk yoğunluğu, sertlik ve SÇKM ile en yüksek pazar değerine sahip genotipler (Grup 3) ve yoğun kırmızı renkli fakat düşük sertlik ve çiçek burnu çürüklüğüne yatkın genotipler (Grup 4) olarak sınıflandırılmıştır. Korelasyon analizleri ise meyve verimi ile kalite özellikleri arasında belirgin bir denge olduğunu, iri ve çok loküllü meyvelerin daha düşük kuru madde içeriğine sahip olabileceğini göstermiştir. Genel olarak, elde edilen bulgular TBA ve küme analizlerinin domates genotipleri arasındaki farklılıkları net biçimde ortaya koyduğunu ve bu sonuçların hem yüksek pazar değerine sahip genotiplerin seçiminde hem de verim veya kalite odaklı ıslah programlarının yönlendirilmesinde önemli katkılar sağlayacağını göstermektedir.

**Atıf Şekli**: Aydın, A., Başak, H., Şavkan, A.N., & Güngör, R., (2026). *İç Anadolu Bölgesinden Toplanan Yerel Domates (Solanum lycopersicum L.) Genotiplerinde Agro-Morfolojik Özelliklerin Belirlenmesi. KSÜ Tarım ve Doğa Derg 29* (2), 291-308. https://doi.org/10.18016/ksutarimdoga.vi.1674372

**To Cite :** Aydın, A., Başak, H., Şavkan, A.N., & Güngör, R., (2025). Determination of Agro-Morphological Characteristics in Local Tomato (*Solanum lycopersicum* L.) Genotypes Collected from Central Anatolia Region. *KSU J. Agric Nat 29*(2), 291-308. https://doi.org/10.18016/ksutarimdoga.vi.1674372

## INTRODUCTION

Tomato, scientifically classified as *Solanum lycopersicum* L., is a highly significant and popular fruit vegetable worldwide (Peralta et al., 2008). The Solanaceae family, to which it belongs, underwent a phylogenetic reclassification in the early 2000s, leading to the integration of the *Lycopersicon* genus back into the *Solanum* genus under a revised naming system. The Lycopersicon group includes the cultivated tomato (*Solanum lycopersicum* L.) and its 12 closest wild relatives. (Peralta et al., 2005, Peralta et al., 2008). In terms of global tomato production, China holds the top position with 70.1 million tonnes, followed by India with 20.4 million tonnes and Turkey with 13.3 million tonnes in 2023 (FAO, 2023). Tomato is highly important due to its large-scale production and consumption, being a top agricultural trade product, its nutritional value for human health, and its versatile usage in the food industry, such as frozen products, tomato paste, ketchup, pickles, and tomato juice. Additionally, tomatoes serve as a substantial source of lycopene, an essential phytochemical with health benefits (Vardanian et al., 2025).

In order to improve tomato crops, it is important to collect and characterise the available germplasm. This characterisation is essential for variety breeding and selection (Fiorani & Schurr, 2013; Salim et al., 2020). In this context, the study of the agro-morphological characteristics and genetic relationships of local tomato genotypes is very important for the conservation of genetic diversity and the improvement of agricultural productivity. The assessment of variability in morpho-agronomic traits is important in the evaluation of these genotypes, as the cultivation of diverse varieties is essential for the adaptability of agricultural systems to climate change. Morphological measurements, including plant height, leaf size, fruit shape, and yield-related traits, play an important role in characterising tomato germplasm and assessing genetic diversity. Several studies have highlighted the value of these traits in understanding genetic diversity in different varieties of vegetables (Kouam et al., 2018; Salim et al., 2020; Islam et al., 2022; Öztürk, 2022; Güngör et al., 2023; Aydın et al., 2024; Rahmadian et al., 2024; Şavkan et al., 2025b).

In addition, morphological evaluation of tomatoes has provided insights into their adaptation to different ecological conditions and the influence of geographical factors on genotypic variability (Öztürk, 2022). Moreover, the diversity observed in traditional cultivars, as evidenced by the extensive morphological diversity among local cultivars, provides further opportunities for breeding programmes aimed at improving fruit quality and yield (Figàs et al., 2015; Şavkan et al., 2024). Phenotypic evaluations play a crucial role in guiding breeding strategies that simultaneously address market preferences and enhance agronomic resilience. (Zhang et al., 2015; Mitul et al., 2016; Islam et al., 2022). In addition, these studies, which are valuable for obtaining a first idea in populations with wide variation where morphological diversity is observable, are frequently used by many researchers as a fast and low-cost method as a preliminary screening study (Figàs et al., 2015; Islam et al., 2022; Aydın & Başak, 2024; Şavkan et al., 2025a).

In breeding programmes, morphological characterisation is important for identifying traits and revealing relationships between genotypes and determining genetic diversity (Hernández-Villareal, 2013; Oduor, 2016). Phenotypic characterisation is used to assess the diversity manifested by morphological characters (Bajracharya et al., 2006). The determination of morphological traits is time-consuming and difficult due to the quantitative nature of the traits (Fiorani & Schurr, 2013). Nevertheless, agro-morphological characterisation studies are required for proper evaluation of many factors such as plant genetic diversity and yield potential (Dharmatti et

al., 2001). In addition, previous researchers working with germplasm of different vegetable species have suggested the use of multivariate analysis (Principal Component Analysis, etc.) and cluster analysis as a valid tool to deal with germplasm collection, characterization, and evaluation of their genetic relationships (Islam et al., 2022; Şavkan & Türkmen, 2023; Şavkan et al., 2024; Yaşar et al., 2025). Although there have been numerous studies on tomato germplasm in different regions of Türkiye, research specifically focusing on the agro-morphological diversity of local genotypes from the Central Anatolia region remains very limited. This gap is significant because the region harbors unique local varieties that are not only adapted to its ecological conditions but also represent valuable genetic resources for breeding. Thus, investigating and documenting the morphological variability of these genotypes is critical for their conservation and for enhancing future breeding strategies targeting yield, fruit quality, and stress tolerance. Therefore, the aim of this study is to characterise the morphological variability of local tomato genotypes collected in Central Anatolia, to evaluate their genetic relationships, and to establish a large core collection for future breeding studies.

## MATERIAL and METHOD

### Plant Material

This study was carried out in 2024 (May-September) in the R&D open-field of Kırşehir Ahi Evran University. The material for the study consisted of 68 local tomato genotypes collected from Central Anatolia (Table 1).

Table 1. Genetic materials used in the study and their sources
*Çizelge 1. Çalışmada kullanılan genetik materyaller ve kaynakları*

| Genotype No | City-District/village | Genotype No | City-District/village |
|---|---|---|---|
| 1 | Kırşehir-Merkez/Karaboğaz | 42 | Kırşehir-Merkez/Boztepe |
| 2 | Kırşehir- Mucur/Aydoğmuş | 43 | Kırşehir-Kaman/Aydınlar |
| 3 | Kırşehir-Merkez/Boztepe | 44 | Kırşehir-Akpınar/Çiftlik Mehmet Ağa |
| 4 | Kırşehir- Mucur/Büyükkayapa | 45 | Kırşehir-Kaman/Kargın-Yenice |
| 5 | Kırşehir-Merkez/Karahıdır | 46 | Kırşehir-Merkez/Dulkadirli |
| 6 | Kırşehir-Kaman/Toklumen | 47 | Kırşehir-Merkez/Çavdırlı- Hacıyusuf |
| 7 | Kırşehir-Kaman/Aydınlar | 48 | Kırşehir-Merkez/Boztepe |
| 8 | Kırşehir-Kaman/Aydınlar | 49 | Kırşehir-Merkez/Karakurt |
| 9 | Kırşehir-Mucur/Yürücek | 50 | Kırşehir-Merkez/ Karahıdır |
| 11 | Kırşehir-Akçakent/Ayvalı | 51 | Kırşehir-Kaman/Kurancılı |
| 12 | Kırşehir-Merkez/Karahıdır | 52 | Kırşehir-Kaman/Toklumen |
| 14 | Kırşehir-Merkez/Karaboğaz | 53 | Kırşehir-Kaman/Kargin-Yenice |
| 15 | Kırşehir-Merkez/Güzler | 54 | Kırşehir-Kaman/Toklumen |
| 18 | Kırşehir-Mucur/Aydoğmuş | 55 | Kırşehir-Kaman/Toklumen |
| 19 | Kırşehir-Merkez/Güzler | 56 | Kırşehir-Kaman/Demirli |
| 20 | Kırşehir-Merkez/Çuğun | 58 | Kırşehir-Kaman/Toklumen |
| 21 | Kırşehir-Merkez/Ecikağıl | 59 | Kırşehir-Kaman/Toklumen |
| 22 | Kırşehir-Merkez/Karaboğaz | 60 | Kırşehir-Kaman/Demirli |
| 23 | Kırşehir-Merkez/Güzler | 61 | Kırşehir-Kaman/Benzer |
| 24 | Kırşehir-Merkez/Kocabey | 62 | Kırşehir-Kaman/Benzer |
| 25 | Kırşehir-Merkez/Kocabey | 63 | Kırşehir-Kaman/Sıdıklı-Büyükaba |
| 26 | Kırşehir-Merkez/Çuğun | 64 | Kırşehir-Kaman/Sıdıklı-Kumarkaç |
| 29 | Kırşehir-Kaman/Benzer | 65 | Kırşehir-Merkez/ Karahıdır |
| 30 | Kırşehir-Kaman/Kargin Meza | 67 | Kırşehir-Kaman/Başköy |
| 32 | Kırşehir-Kaman/Müderris | 68 | Kırşehir-Mucur/Aydoğmuş |
| 33 | Kırşehir-Akpınar/Merkez | 69 | Kırşehir-Merkez/Karakurt |
| 34 | Kırşehir-Akpınar/Merkez | 70 | Kırşehir-Merkez/Karakurt |
| 35 | Kırşehir-Merkez/ Karahıdır | 71 | Kırşehir-Merkez/Karakurt |
| 36 | Kırşehir-Merkez/ Karahıdır | 72 | Kırşehir-Merkez/Karakurt |
| 37 | Kırşehir-Kaman/Toklumen | 73 | Kırşehir-Merkez/Karakurt |
| 38 | Kırşehir-Kaman/Savcılı | 75 | Kırşehir-Merkez/Karakurt |
| 39 | Kırşehir-Kaman/Çağırgan | 76 | Kırşehir-Merkez/Karakurt |
| 40 | Kırşehir-Kaman/Çağırgan | 78 | Kırşehir-Merkez/Karakurt |
| 41 | Kırşehir-Kaman/Çağırgan | 79 | Kırşehir-Merkez/Karakurt |

## Agro-Morphological characters

According to seed emergence, ten plants per genotype were grown in a completely randomized design with double rows, planted on ridges spaced at 0.7 m intervals and a spacing of 0.4 m between and within rows. Standard field management practices were applied throughout the growing season: irrigation was managed to maintain adequate soil moisture, hand weeding was performed to suppress weeds, fertilization followed recommended agronomic practices for tomato cultivation, and pests and diseases were managed using integrated pest management (IPM) techniques (Aybak, 2015).

A total of ten plants of each genotype were cultivated. During the characterisation phase, genotypes that demonstrated variations in fruit characteristics were grouped within their own genotypes and evaluated as separate genotypes. Consequently, the number of genotypes rose from 68 to 116. 116 genotypes were characterized using 30 morphological characters (18 qualitative and 12 quantitative), and quantitative characters were measured while qualitative characters were observed (Table 2). In the experiment, morphological and pomological characterization was carried out in terms of plant and fruit traits according to IPGRI's description list for tomato and UPOV (2024) criteria (Protocol for tests of difference, uniformity and stability, UPOV (TG/44/12).

Table 2. Morphological and pomological trait descriptions
*Çizelge 2. Morfolojik ve pomolojik özelliklerin tanımı*

| |
|---|
| 1. Plant growth habit: (1) Determinate, (2) Indeterminate |
| 2. Plant vigor: (1) Weak, (2) Medium, (3) Strong |
| 3. Stem pubescence: (1): none, (2): slight, (3): moderate, (4): dense |
| 4. Leaf attitude: (1): semi-erect, (2): horizontal, (3): semi-drooping, (4): mixed |
| 5. Leaf colour: (1): light green, (2): medium green, (3): dark green |
| 6. Internode length (cm): Measured with a ruler |
| 7. Internode diameter (mm): Measured with a caliper |
| 8. Inflorescence type: (1) Simple, (2) Compound, (3) Mixed |
| 9. Number of fruits per inflorescence (count): The number of fruits at each developmental stage was recorded. |
| 10. Green shoulder before maturity: (1) Present, (0) Absent |
| 11. Fruit shape: (1) Oval, (2) Round, (3) Flat oval, (4) Flat round, (5) Slightly flat oval, (6) Slightly flat round, (7) Ribbed flat oval, (8) Ribbed flat round, (9) Irregular ribbed flat |
| 12. Ripe fruit colour: (1) Red, (2) Pink |
| 13. Shoulder on ripe fruit: (1) Present, (0) Absent |
| 14. Blossom-end rot: 0 None, 1 Slight, 2 Moderate, 3 Severe |
| 15. Blossom-end shape: (1) Dot, (2) Star, (3) Irregular, (4) Radiate |
| 16. Flesh colour of ripe fruit: (1) Light red, (2) Pinkish red, (3) Red, (4) Dark red |
| 17. Transverse fruit shape: (1) Round, (2) Angular, (3) Irregular, (4) Oval |
| 18. Number of locules: (1) ≤3, (2) 3–5, (3) 5–7, (4) ≥7 |
| 19. Locule size: (1) Small, (2) Medium, (3) Large, (4) Irregular |
| 20. Internal fruit vascularization: (0) None, (1) Slight, (2) Moderate, (3) Intense |
| 21. Average fruit weight (g): Measured with a scale. Recorded using a digital scale with precision up to 0.01 g |
| 22. Fruit width (cm): Measured with a ruler |
| 23. Fruit height (cm): Measured with a ruler |
| 24. Flesh thickness of ripe fruit (mm): Measured with a caliper |
| 25. Skin thickness of ripe fruit (mm): Measured with a caliper |
| 26. Fruit colour L* value: Measured using a Minolta colourimeter (Model Cr-100, Minolta Camera, Osaka, Japan) |
| 27. Fruit colour a* value: Measured using a Minolta colourimeter (Model Cr-100, Minolta Camera, Osaka, Japan) |
| 28. Fruit colour b* value: Measured using a Minolta colourimeter (Model Cr-100, Minolta Camera, Osaka, Japan) |
| 29. Soluble solids content (%): Measured using a digital refractometer (Hanna HI96801 digital refractometer) |
| 30. Fruit firmness (kg/N): Measured using a penetrometer (PCEPTR 200 penetrometer) |

## Statistical analysis

Histogram graphs, principal component analysis (PCA), and cluster analyses were performed using Minitab 22 statistical software. In PCA, calculations were based on the correlation matrix, and the obtained components were evaluated according to the Kaiser criterion (eigenvalue > 1). In cluster analyses, the Euclidean distance measure was used, and grouping was performed using Ward's minimum variance method. Qualitative traits were converted into numerical values on ordinal scales based on IPGRI and UPOV definitions to be included in the analyses, and all data were appropriately standardized.

## RESULTS and DISCUSSION

### Agro-Morphological Characteristics

The distribution of plant growth habits among 116 tomato genotypes is presented. The data indicate that the vast majority of the genotypes (115) exhibit determinate growth, while only a single genotype displays an indeterminate growth habit. This suggests that most of the evaluated genotypes reach a certain growth limit and then cease further development. Regarding plant vigor, the majority of genotypes were observed to have medium (74) or strong (35) vigor levels, while only a few genotypes (7) exhibited weak vigor. This finding indicates that the evaluated tomato genotypes generally possess a healthy and robust plant structure. Assessment of stem pubescence levels revealed that 73 genotypes exhibited slight pubescence, while 43 genotypes showed moderate pubescence. No genotypes were identified with either no pubescence or dense pubescence. These results suggest that slight to moderate pubescence is the predominant characteristic among the studied genotypes. Sönmez et al. (2015) reported that 15 genotypes had low hairiness, 44 genotypes had medium hairiness, and 2 genotypes had high hairiness in their study on local tomato genotypes. In contrast to our study, Islam et al. (2022) reported that only one genotype showed a definite growth habit, while most of the genotypes showed an indeterminate growth habit. Regarding the stem hairiness, 6 genotypes showed intermediate, 5 genotypes showed dense, and one genotype showed a sparse pubescence density. It is predicted that this difference is due to the genotypes.

In terms of leaf attitude, most of the genotypes (100) exhibited a semi-drooping leaf orientation. Other leaf attitudes (semi-erect, horizontal, and mixed) were observed in only a few genotypes. This indicates that the semi-drooping leaf type is predominant in the evaluated material. Similarly, Turhan and Şeniz (2009) observed the leaf posture of the genotypes as semi-upright and horizontal in their study. For leaf colour, the majority of genotypes (111) exhibited dark green leaves. The number of genotypes with light or medium green leaf colour was notably low. This may indicate that most of the genotypes possess higher chlorophyll content, which could contribute to greater photosynthetic capacity. Başak et al. (2025a) reported that decreasing leaf area and a decrease in chlorophyll density were associated with more pronounced decreases in photosynthetic rates. Yardım et al. (2024) reported that green colour intensity in leaves was intense in one genotype and moderate in all other genotypes. Zhou et al. (2015) revealed that leaf traits constitute an important part of phenotypic variation. Saka (2023) reported that among the genotypes, 17 of the leaves had light, 6 of the leaves had dark, and 35 of the leaves had medium dark green colour intensity. Considering internode length, most genotypes were distributed between 6.25 and 10.75 cm. Genotypes with extremely short or long internode lengths were fewer in number. This suggests that the majority of the genotypes exhibit moderate internode length, indicating a balanced growth pattern (Figure 1).

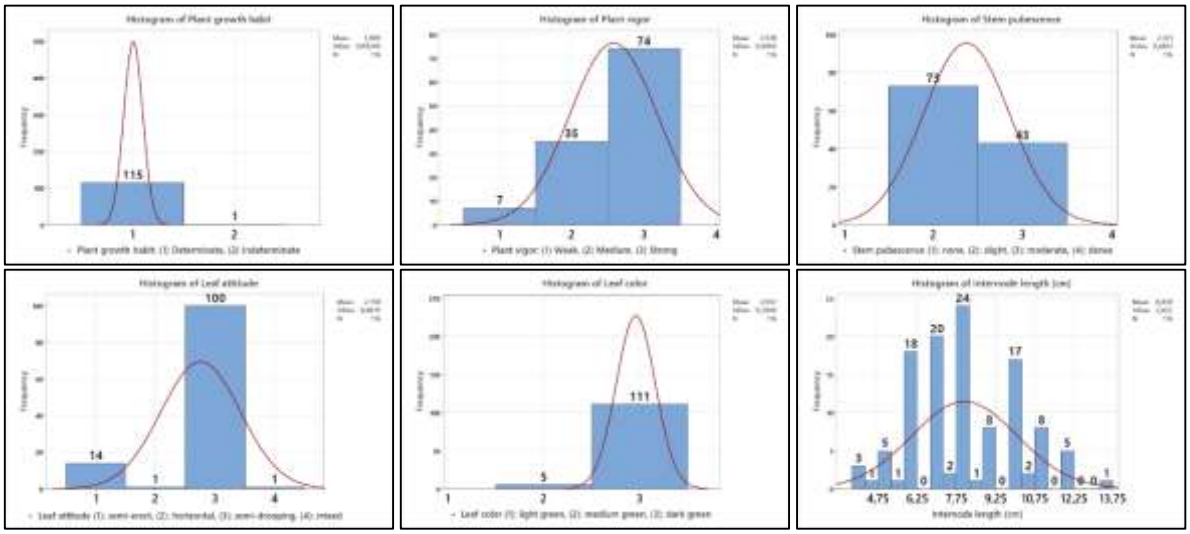


Figure 1. Histogram charts illustrating the distribution of plant growth habit, plant vigor, stem pubescence, leaf attitude, leaf colour, and internode length (cm) among tomato genotypes.

*Şekil 1. Domates genotipleri arasında bitki büyüme alışkanlığı, bitki canlılığı, gövde tüylenmesi, yaprak tutumu, yaprak rengi ve boğum arası uzunluğunun (cm) dağılımını gösteren histogram grafikleri.*

An examination of the distribution of internode diameter revealed that most genotypes fell within the range of 10.5 to 16.5 mm (Figure 2). This indicates that the majority of the genotypes possess stems of medium thickness. Genotypes with extremely thin or thick internode diameters were found to be relatively few in number. Parallel to our results, Güngör et al. (2023) reported that the stem diameter of 14 tomato genotypes with different fruit types ranged from 11.04 to 19.25 mm. In terms of inflorescence type, a large proportion of the genotypes (112) exhibited a simple inflorescence structure. Only a small number of genotypes displayed compound (3 genotypes) or mixed (1

genotype) inflorescences. These findings suggest that the simple inflorescence type is predominant among the evaluated genotypes. In the study of Salim et al. (2020), a wide variation in inflorescence type was observed among different genotypes. Analysis of the number of fruits per inflorescence showed that most genotypes bore 2, 3, or 4 fruits. The highest frequencies were observed at 3 fruits (37 genotypes) and 2 fruits (32 genotypes). Genotypes bearing more than five fruits per inflorescence were rare. These results indicate that a moderate fruit set per inflorescence is common among the studied materials. While studying tomato germplasm, Kouam et al. (2018) also reported that the number of fruits per inflorescence ranged from 3.10 to 8.97. In the study of exotic tomato genotypes, significant variation was reported in the number of fruit plants, ranging from 4.56 to 9.22 (Islam et al., 2022). However, the difference among the flowering types of genotypes is probably due to including the cherry tomato (Binatomato-10) in the studied genotypes. Regarding the presence of green shoulder before maturity, 67 genotypes did not exhibit this trait, while 49 genotypes showed green shoulder formation. This distribution suggests that most genotypes present a uniform fruit colour before ripening, which may be considered a favorable characteristic in terms of commercial fruit quality. Twenty-one out of the genotypes had no green shoulder, except for one in Salim et al. (2020). The presence or absence of green shoulder excursions has been reported in previous studies (Bhattarai et al., 2018; Sacco et al., 2015). The histogram of fruit shape revealed substantial variation among the genotypes (Figure 2). The largest number of genotypes (50) corresponded to the shape represented by scale number 9, indicating that this fruit form is dominant. Other shapes, particularly those represented by scale numbers 4, 5, and 6, were observed in fewer genotypes. This reflects a wide morphological diversity in fruit shape and highlights the genetic variation present within the study population. Yardım et al. (2024) reported that the longitudinal section shapes of the genotypes were found to be elliptical in 2 genotypes, flat in 1 genotype, and oval in 1 genotype. Based on ripe fruit colour, the majority of genotypes (93) produced red fruits, while 23 genotypes exhibited pink fruit colour. This distribution demonstrates that red fruit colour is dominant among the studied genotypes (Figure 2). Oğuz (2010) found the materials observed as red, dark red, and pink when he examined them in terms of fruit colour in his study, while Yardım et al. (2024) reported that the ripeness colour of all genotypes was determined as red.

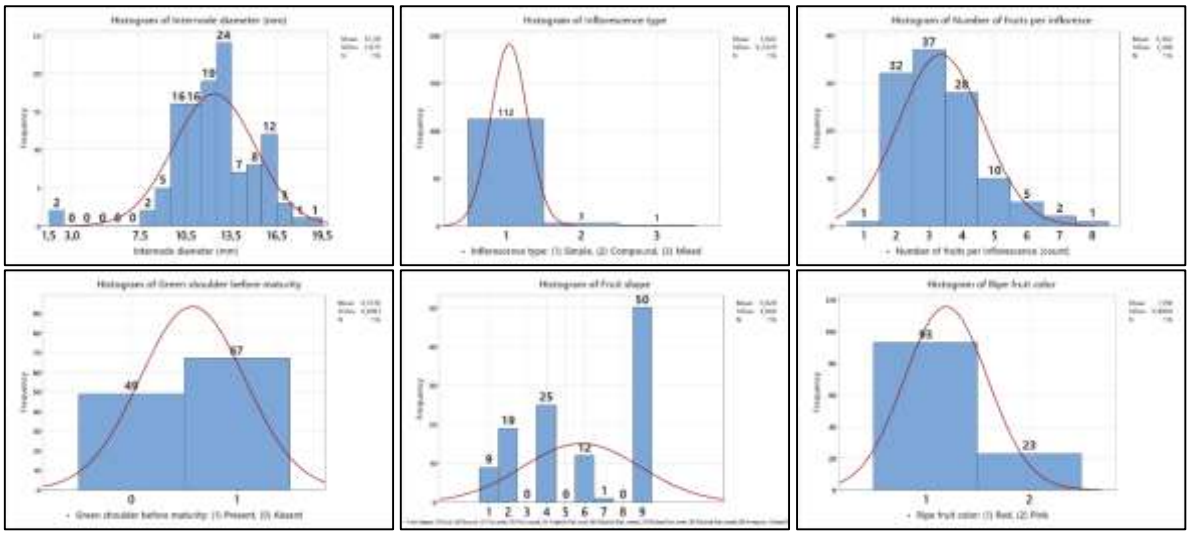

Figure 2. Histogram charts illustrating the distribution of internode diameter, inflorescence type, number of fruits per inflorescence, green shoulder before maturity, fruit shape, and ripe fruit colour among tomato genotypes.

*Şekil 2. Boğum arası çapı, çiçeklenme tipi, çiçeklenme başına meyve sayısı, olgunluk öncesi yeşil omuz, meyve şekli ve olgun meyve renginin domates genotipleri arasındaki dağılımını gösteren histogram grafikleri.*

Data showed that 108 out of 116 tomato genotypes exhibited the presence of a shoulder on ripe fruits, whereas only 8 genotypes lacked this characteristic. Similar to our results, Tembe et al. (2018) examined the green collars of local tomato genotypes in a study and found green collars on fruits in approximately 80% of the genotypes. Regarding blossom-end rot severity, the majority of genotypes (84) did not display any symptoms of this physiological disorder. Slight rot was observed in 31 genotypes, while moderate and severe levels were detected in only one genotype each. This suggests that most of the evaluated genotypes are generally tolerant to this stress-related disorder. In terms of blossom-end shape, the majority of genotypes (81) exhibited an irregular shape. The "dot" type was observed in 33 genotypes, whereas the "star" and "radiate" types were found in fewer genotypes. These findings indicate that irregular morphology is predominant at the blossom end of the fruit. In our study, a general trend was observed whereby the size of the blossom-end rot increased proportionally with fruit size. This

observation is consistent with previous reports indicating a positive correlation between fruit size and the incidence of blossom-end rot (BER) in tomatoes (Marcelis & Ho, 1999; Heuvelink & Körner, 2001). Furthermore, BER has not been reported in wild relatives or small-fruited tomato varieties (Ho & White, 2005). The fact that BER occurs exclusively in cultivated tomato lines suggests that domestication and the selection for larger fruits may have contributed to the emergence of this disorder. Examination of the flesh colour of ripe fruit revealed that most genotypes belonged to the light red (57) and dark red (43) categories. Fewer genotypes were classified as pinkish red (11) and red (5). This distribution demonstrates that light and dark red tones are dominant flesh colour traits among the studied genotypes. Yardım et al. (2024) observed that the flesh colour of the genotypes was red in Türkiye genotypes and pink in Kyrgyzstan genotypes. Again, Çukadar (2011) determined the flesh colour of all local tomato genotypes as red in his study. With respect to transverse fruit shape, most genotypes (76) exhibited a round shape. Irregular (31) and angular (9) shapes were less common, while the oval shape was not observed in any genotype. This suggests that round fruit morphology is prevalent among the evaluated materials. It was reported that four genotypes had oval fruit shape, 7 genotypes had round fruit shape, and Binatomato-10 had long rectangular fruit shape (Islam et al., 2022). In terms of the number of locules, the highest number of genotypes (83) had fruits with four locules. This was followed by genotypes with 5–7 locules (16), 2–3 locules (12), and a small number (5) with a single locule. These results indicate that a four-loculed fruit structure is dominant among the studied tomato genotypes (Figure 3). Salim et al. (2020) reported statistically significant variation in tomato genotypes for locules per fruit, ranging from 2.00 to 9.93 among genotypes.

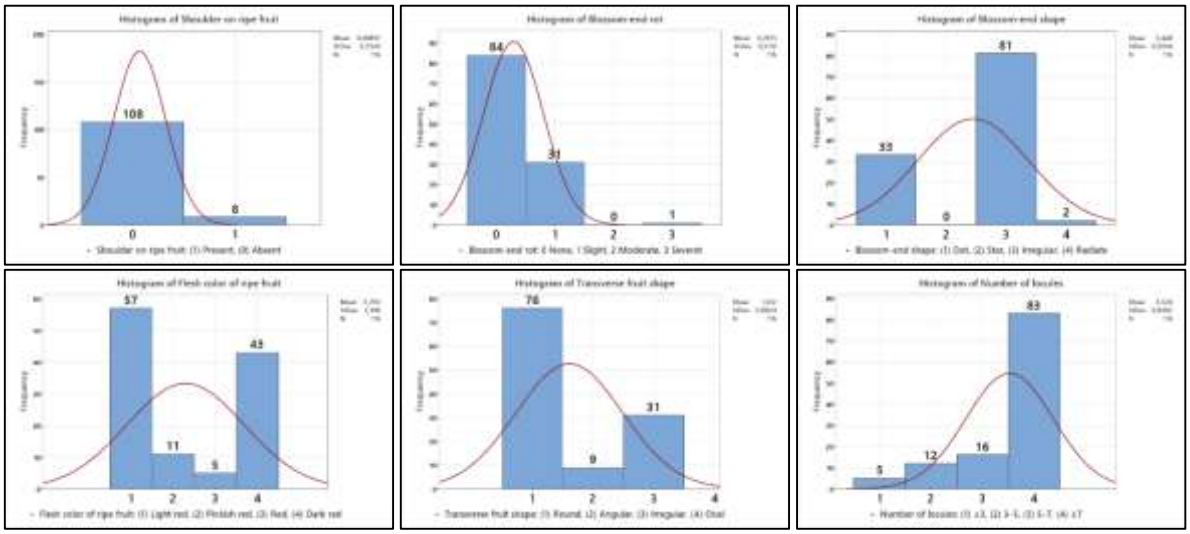


Figure 3. Histogram charts illustrating the distribution of shoulders on ripe fruit, blossom-end rot severity, blossom-end shape, flesh colour of ripe fruit, transverse fruit shape, and number of locules among tomato genotypes.

*Şekil 3. Olgun meyvede omuz dağılımı, çiçek ucu çürüklüğü şiddeti, çiçek ucu şekli, olgun meyvenin et rengi, enine meyve şekli ve domates genotipleri arasında lokul sayısını gösteren histogram grafikleri.*

According to the histogram data (Figure 4), the majority of genotypes (76) exhibited irregular locule sizes. The number of genotypes with medium and large locule sizes was equal (16 each), while those with small locule sizes were fewer. This indicates a high degree of variation among genotypes in terms of locule size, with irregular locule structure being the predominant type. Yardım et al. (2024) determined the largest fruit kernel house size as 50.01 mm and since fruit kernel house size is an important feature for seed production, they predicted that this genotype would provide higher yield in seed production compared to other genotypes. In terms of internal fruit vascularization, most genotypes (83) showed no signs of this trait, indicating the absence of internal vascularization. Slight vascularization was observed in 20 genotypes, and moderate vascularization in 13 genotypes, while no genotypes exhibited intense vascularization. These findings suggest that the majority of the genotypes possess homogeneous internal tissue, which may be considered favorable in terms of fruit quality.
Previous studies have reported that the size of vascular bundles at the basal part of the fruit is associated with calcium fertilization (Paiva et al., 2023). In our study, it can be inferred that genotypes with no visible vascular development in the blossom-end region may be more efficient in calcium utilization. Regarding average fruit weight, the majority of genotypes ranged between 75 and 225 grams (Table 3). The most frequent weight intervals were 75–125 g (25 genotypes) and 125–225 g (40 genotypes). The number of genotypes with higher fruit weights gradually decreased. This distribution suggests that medium-sized fruits are predominant among the evaluated genotypes. In the genotypes analysed, a significant variation was found for the fruit yield per plant (FYP) trait.

Table 3. Descriptive statistics of tomato traits.
*Çizelge 3. Domates özelliklerinin tanımlayıcı istatistikleri.*

| Trait | Minimum | Maximum | Mean | Std. Deviation | Variance | CV (%) |
|---|---|---|---|---|---|---|
| Internode length | 4.0 | 13.3 | 8.06 | 2.02 | 4.09 | 25.08 |
| Internode diameter | 1.57 | 19.09 | 12.38 | 2.67 | 7.15 | 21.59 |
| Average fruit weight | 19.59 | 638.0 | 200.92 | 133.98 | 17951.08 | 66.68 |
| Fruit width | 3.0 | 13.0 | 7.77 | 2.17 | 4.73 | 27.97 |
| Fruit height | 2.0 | 9.2 | 5.08 | 1.36 | 1.84 | 26.65 |
| Flesh thickness of ripe fruit | 1.29 | 7.88 | 4.83 | 1.54 | 2.36 | 31.83 |
| Skin thickness of ripe fruit | 0.09 | 3.13 | 1.38 | 0.68 | 0.46 | 49.20 |
| Fruit colour L* value | 29.06 | 97.99 | 43.21 | 9.6 | 92.25 | 22.22 |
| Fruit colour a* value | 7.53 | 77.78 | 33.05 | 11.72 | 137.37 | 35.46 |
| Fruit colour b* value | 7.5 | 35.06 | 18.62 | 4.91 | 24.13 | 26.37 |
| Soluble solids content | 3.17 | 10.4 | 6.69 | 1.44 | 2.08 | 21.56 |
| Fruit firmness | 0.3 | 6.6 | 1.69 | 0.88 | 0.78 | 52.17 |

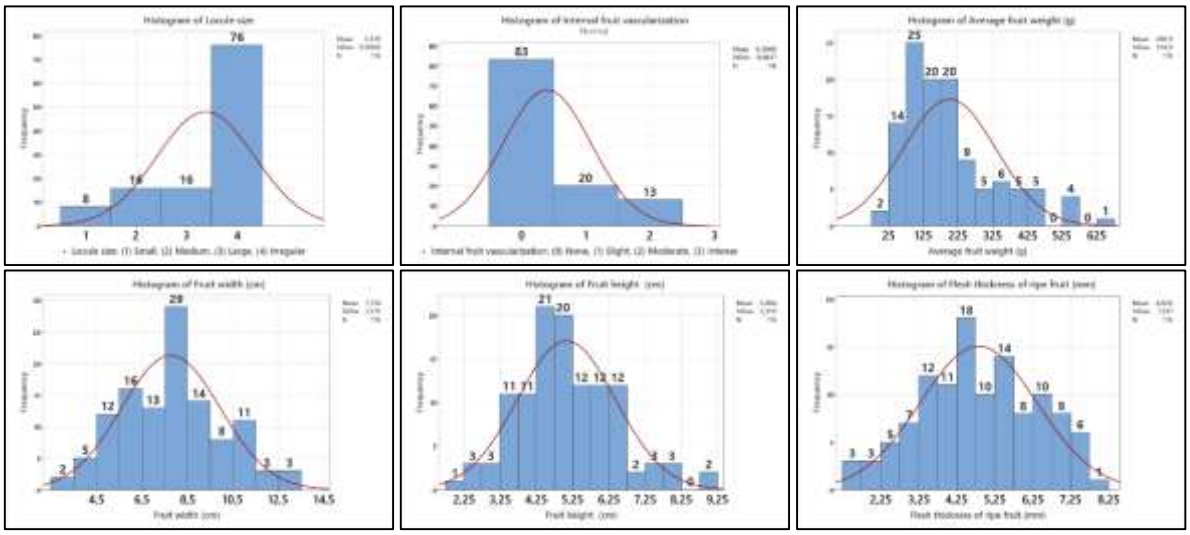

Figure 4. Histogram charts illustrating the distribution of locule size, internal fruit vascularization, average fruit weight (g), fruit width (cm), fruit height (cm), and flesh thickness of ripe fruit (mm) among 116 tomato genotypes.

*Şekil 4. Lokul büyüklüğü, iç meyve damarlanması, ortalama meyve ağırlığı (g), meyve genişliği (cm), meyve yüksekliği (cm) ve olgun meyve eti kalınlığının (mm) domates genotipleri arasındaki dağılımını gösteren histogram grafikleri.*

Islam et al. (2022) reported that fruit yield plant$^{-1}$ in tomato germplasm ranged from 0.422 to 1.98 kg. Similarly, a significant difference in fruit yield plant$^{-1}$ in tomato was also reported by other studies (Ali et al., 2016; Kouam et al., 2018). According to the distribution of fruit width, most genotypes had widths ranging between 6.5 and 8.5 cm, with the highest frequency observed in the 7.5–8.5 cm range (29 genotypes). This indicates that the majority of the evaluated tomato genotypes produce fruits of medium width. Fruit diameter also differed significantly among the genotypes. Salim et al. (2020) reported fruit diameters ranging from 3.63 to 8.15 cm, while Yesmin et al. (2014) reported fruit diameters ranging from 3.64 to 5.71 cm in winter tomato cultivars. Kouam et al. (2018) reported that fruit diameters ranging from 3.74 to 5.34 cm were also recorded in cultivated tomato. In this study, we found slightly larger fruits. It may be due to the influence of the environment or the characteristics of the genotypes themselves, and/or both. In terms of fruit height, most genotypes clustered within the 4.25–5.25 cm range. The highest frequencies were recorded in the 4.25–4.75 cm (21 genotypes) and 4.75–5.25 cm (20 genotypes) intervals. Fewer genotypes exhibited either shorter or taller fruit heights, suggesting a relatively balanced fruit shape across the population. Salim et al. (2020) reported fruit length ranging from 3.91 to 6.57 cm, with the longest fruit being 6.57 cm and the shortest being 3.91 cm. Similarly, Yesmin et al. (2014) reported that fruit length ranged from 3.24 to 5.48 cm in tomato genotypes. The data on flesh thickness of ripe fruit indicated that most genotypes had flesh thicknesses ranging from 3.25 to 6.75 mm. The highest frequencies were observed in the 4.25–4.75 mm (18 genotypes) and 5.25–5.75 mm (14 genotypes) intervals. Genotypes with extremely thin or thick fruit flesh were less common, indicating that most genotypes possess medium-level flesh thickness, which is desirable for commercial purposes (Figure 4). Fruit flesh thickness also differed significantly among the genotypes. Salim et al. (2020) found that the pericarp thickness in tomato genotypes was between 8.07-4.40 mm, while Vishwanath et al.

(2014) found pericarp thickness between 8.4-3.6 mm. The mean pericarp thickness was 6.33-3.12 mm in Yesmin et al. (2014), while Demir and Ünlü (2023) reported a pericarp thickness of 6.81 -10.54 mm. This difference may be due to the difference in genotypes between the studies.

An analysis of the distribution of skin thickness in ripe fruit revealed that most genotypes had a skin thickness ranging between 0.9 and 1.7 mm (Figure 5). The highest frequency was observed in the 1.1–1.3 mm interval, with 20 genotypes. Genotypes with thinner or thicker skin were relatively few in number. These results indicate that moderate skin thickness is prevalent among the evaluated tomato genotypes. The distribution of L* values showed that most genotypes ranged between 32.5 and 57.5 (Figure 5). The highest frequencies were recorded in the 42.5–47.5 interval (30 genotypes) and the 32.5–37.5 interval (29 genotypes). This indicates that the majority of the fruits had medium lightness levels, suggesting balanced brightness in fruit colour. For the a* values, the majority of genotypes were distributed within the 27.5–42.5 range (Figure 5), with the highest frequencies observed in the 32.5–37.5 interval (35 genotypes) and the 27.5–32.5 interval (32 genotypes). These findings indicate that red tones are dominant in fruit colour among the studied genotypes. The b* value distribution revealed that most genotypes were concentrated in the 13.75–23.75 range (Figure 5). The highest frequency was found in the 16.25–17.75 interval, with 29 genotypes. This suggests that yellow colour expression was moderate and balanced in most genotypes, contributing to overall fruit colour uniformity. Yardım et al. (2024) reported that the L value of the genotypes was in the range of 36.07-41.33, the a value was in the range of 20.85-30.90 and the b value was in the range of 17.73-27.26, while Renna et al. (2019) determined the L value between 36.4-44.3, a value between 27.70-30.9, b value between 31.2-37.7. Although our study is numerically similar to these values, this difference may be due to the difference in genotypes between the studies. The distribution of soluble solids content showed that most genotypes were concentrated within the 4.25–7.75% range (Figure 5). The highest frequencies were observed in the 6.25–6.75% (18 genotypes) and 6.75–7.25% (15 genotypes) intervals. This indicates that the majority of the fruits had moderate levels of sugar content. TSS content is important in the selection of the fermentation method/duration during seed extraction and processing. Van Berloo et al. (2008) calculated Brix values in a collection of 94 cultivars and obtained results similar to those in the mean, minimum, and maximum Brix values collection (5.17, 3.83, and 9.27, respectively). Our results are in partial agreement with Salim et al. (2020), who reported TSS contents ranging from 5.51 to 2.97%. Similarly, Islam et al. (2022) reported that the TSS content ranged from 3.67 to 5.60. Fruit firmness data revealed that most genotypes exhibited firmness values between 0.75 and 2.75 kg (Figure 5). The highest frequencies were recorded in the 1.25–1.75 kg (34 genotypes) and 0.75–1.25 kg (29 genotypes) intervals. These results suggest that the majority of genotypes produced fruits with moderate firmness, which is desirable for postharvest quality and shelf life (Figure 5). Yardım et al. (2024) reported that the firmest fruit flesh in ripe tomato fruit was 4.50% and the softest fruit flesh was 1.76%.

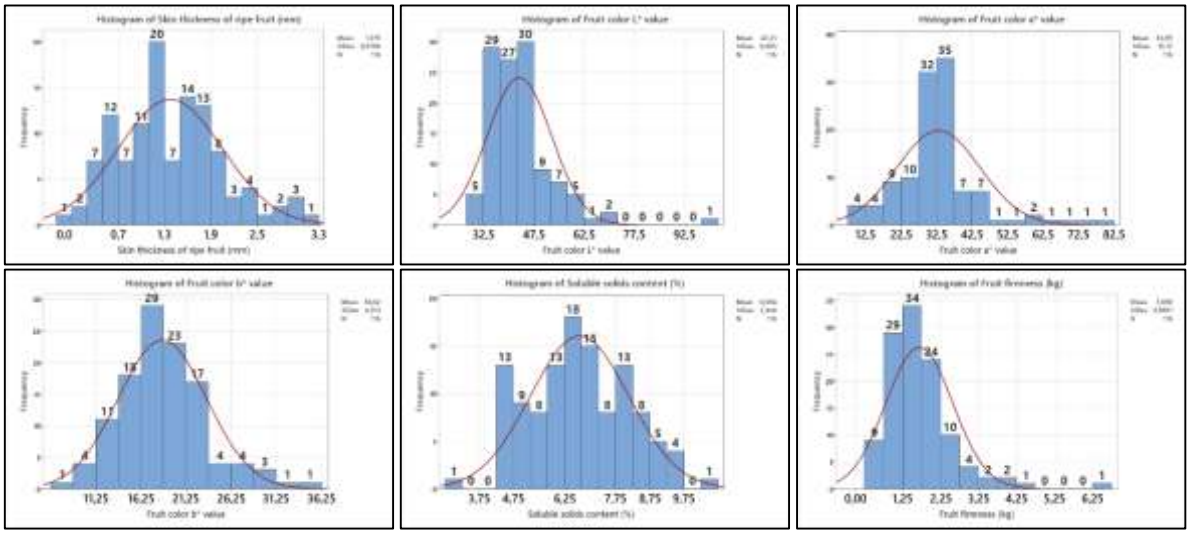

Figure 5. Histogram charts illustrating the distribution of skin thickness of ripe fruit, fruit colour parameters (L*, a*, b*), soluble solids content, and fruit firmness among tomato genotypes.

*Şekil 5. Olgun meyve kabuğu kalınlığı, meyve rengi parametreleri (L*, a*, b*), çözünür katı madde içeriği ve meyve sertliğinin domates genotipleri arasındaki dağılımını gösteren histogram grafikleri.*

In this study, descriptive statistics for 12 different morphological and quality traits of the evaluated tomato genotypes were analyzed. The obtained minimum, maximum, mean, standard deviation, and variance values revealed a considerable level of variation among the genotypes. Among morphological traits, the highest coefficient of variation (CV) was observed in fruit weight (66.68%), indicating wide diversity among genotypes and strong

discriminatory power for breeding. Similarly, fruit skin thickness (49.20%) and firmness (52.17%) showed high variability. Flesh thickness (31.83%) and a* value (35.46%) exhibited moderate to high variation, highlighting their importance for quality. Fruit width, height, and b* value (26–28%) showed moderate variation, while plant traits (internode length 25.08%, diameter 21.59%) and SSC (21.56%) displayed relatively lower diversity. Overall, fruit-related traits, especially weight, firmness, and skin thickness, emerged as the most powerful selection criteria in breeding programs ( Table 3).

## Principal Component Analysis

PCA analysis has been used in different crops, including tomato, to assess morphological variation and establish genetic relationships between germplasms (Bernousi et al., 2011; Gerrano et al., 2015; Aydın & Yetişir, 2023; Şavkan &Türkmen, 2023; Aydın, 2024a; Aydın, 2024b; Başak et al., 2025b; Şavkan et al., 2025b). The principal component (PC) axes, eigenvalues, variation, and cumulative variation ratios obtained as a result of principal component analysis are presented in detail in Table 4. In the studies, it has been stated that PCA analysis can be used effectively when the first two components explain more than 25% of the variance (Mohammadi & Prasanna, 2003). In our study, the first two axes explained 31.4% of the variation (Table 4). An eigenvalue greater than 1 indicates that the principal component values are reliable (Mohammadi & Prasanna, 2003). In our study, the eigenvalues of the first ten components ranged from 1.00 to 5.31. The PCA loading plot illustrates the relationships between morphological traits of tomato genotypes and their contributions to the first ten principal components, which together explain 69.1% of the total variation (Table 4). Another study on tomato reported that the first three PC axes explained 48.9% of the total variation (Kıymacı et al., 2024). Bhattarai et al. (2016) obtained five principal component axes in 71 tomato genotypes, which explained more than 92% of the total variation.

Table 4. Eigenanalysis based on agro-morphological characteristics.
*Çizelge 4. Tarımsal morfolojik özelliklere göre öz analizi.*

| Eigenanalysis of the Correlation Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Eigenvalue | 5,3109 | 4,1013 | 2,1693 | 1,812 | 1,5932 | 1,3218 | 1,2212 | 1,1563 | 1,0385 | 1,0052 |
| Proportion | 0,177 | 0,137 | 0,072 | 0,06 | 0,053 | 0,044 | 0,041 | 0,039 | 0,035 | 0,034 |
| Cumulative | 0,177 | 0,314 | 0,386 | 0,446 | 0,5 | 0,544 | 0,584 | 0,623 | 0,657 | 0,691 |
| **Eigenvectors** | | | | | | | | | | |
| **Variable** | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 |
| Plant growth habit | 0,075 | -0,003 | 0,009 | -0,276 | -0,124 | 0,115 | -0,255 | -0,38 | -0,373 | -0,302 |
| Plant vigor | 0,141 | -0,271 | 0,102 | 0,146 | -0,196 | 0,133 | 0,118 | 0,051 | -0,106 | 0,06 |
| Stem pubescence | 0,084 | -0,112 | -0,109 | -0,443 | -0,019 | 0,247 | 0,21 | -0,162 | 0,225 | 0,091 |
| Leaf attitude | -0,02 | -0,072 | 0,261 | 0,551 | 0,097 | 0,194 | -0,003 | 0,061 | 0,015 | 0,108 |
| Leaf colour | 0,049 | -0,082 | 0,055 | -0,046 | -0,082 | 0,103 | 0,036 | 0,542 | -0,367 | -0,32 |
| Internode length | -0,01 | -0,058 | 0,071 | 0,206 | -0,452 | 0,002 | 0,378 | -0,145 | -0,026 | 0,333 |
| Internode diameter | 0,153 | -0,082 | -0,1 | -0,017 | 0,162 | 0,197 | 0,474 | 0,113 | -0,223 | -0,218 |
| Inflorescence type | -0,045 | -0,056 | 0,013 | -0,136 | 0,352 | 0,349 | -0,024 | 0,253 | -0,274 | 0,512 |
| Number of fruits per infloresce | -0,281 | -0,083 | -0,001 | -0,141 | -0,043 | 0,032 | -0,246 | 0,174 | 0,044 | 0,286 |
| Green shoulder before maturity | 0,197 | 0,178 | 0,087 | 0,164 | 0,092 | 0,391 | -0,12 | -0,121 | 0,066 | -0,041 |
| Fruit shape | 0,29 | 0,132 | 0,102 | -0,093 | -0,112 | 0,208 | 0,23 | -0,048 | 0,041 | -0,033 |
| Ripe fruit colour | 0,078 | 0,237 | 0,001 | -0,21 | 0,25 | -0,153 | 0,149 | 0,111 | 0,26 | 0,071 |
| Shoulder on ripe fruit | 0,138 | -0,047 | 0,028 | 0,101 | 0,017 | 0,281 | -0,117 | 0,254 | 0,603 | -0,327 |
| Blossom-end rot | -0,001 | 0,181 | 0,272 | -0,118 | 0,035 | 0,37 | -0,113 | -0,292 | -0,011 | 0,028 |
| Blossom-end shape | 0,263 | 0,081 | 0,178 | 0,156 | 0,085 | -0,196 | -0,178 | 0,016 | -0,025 | 0,015 |
| Flesh colour of ripe fruit | -0,163 | 0,182 | -0,346 | -0,018 | -0,189 | 0,196 | -0,061 | 0,248 | 0,048 | -0,023 |
| Transverse fruit shape | 0,275 | 0,119 | 0,058 | -0,093 | -0,25 | -0,093 | 0,025 | 0,156 | -0,051 | 0,097 |
| Number of locules | 0,292 | 0,13 | 0,04 | 0,033 | 0,102 | -0,086 | -0,045 | 0,014 | -0,156 | 0,032 |
| Locule size | 0,214 | 0,063 | 0,166 | -0,104 | -0,172 | -0,173 | -0,322 | 0,212 | -0,055 | 0,004 |
| Internal fruit vascularization | 0,216 | -0,016 | 0,203 | -0,148 | -0,147 | -0,181 | 0,043 | 0,074 | 0,195 | 0,239 |
| Average fruit weight | 0,334 | -0,197 | -0,143 | -0,012 | -0,022 | 0,124 | -0,179 | -0,008 | 0,045 | 0,13 |
| Fruit width | 0,372 | -0,126 | -0,08 | -0,019 | -0,051 | 0,038 | -0,115 | -0,016 | -0,01 | 0,171 |
| Fruit height | 0,157 | -0,343 | -0,198 | -0,028 | 0,073 | 0 | -0,246 | 0,027 | -0,032 | 0,067 |
| Flesh thickness of ripe fruit | 0,002 | -0,412 | -0,064 | 0,142 | 0,047 | -0,045 | -0,024 | -0,106 | 0,061 | -0,127 |
| Skin thickness of ripe fruit | 0,001 | -0,343 | -0,165 | -0,02 | 0,129 | -0,012 | -0,088 | -0,147 | 0,091 | 0,051 |
| Fruit colour L* value | -0,12 | -0,118 | 0,414 | -0,295 | 0,084 | 0,031 | 0,035 | 0,186 | 0,075 | -0,007 |
| Fruit colour a* value | -0,229 | -0,077 | 0,082 | -0,02 | -0,397 | 0,266 | -0,19 | 0,055 | 0,034 | 0,029 |
| Fruit colour b* value | -0,12 | -0,254 | 0,425 | -0,148 | -0,142 | -0,037 | 0,019 | -0,029 | 0,035 | -0,148 |
| Soluble solids content | -0,074 | 0,312 | 0,051 | 0,134 | 0,025 | 0,098 | -0,185 | -0,073 | -0,063 | 0,069 |
| Fruit firmness | -0,046 | -0,159 | 0,339 | 0,006 | 0,329 | -0,072 | 0,036 | -0,086 | -0,038 | -0,025 |

Principal component analysis (PCA) revealed the main sources of variation among the genotypes. The first two principal components (PC1 = 17.7%; PC2 = 13.7%) explained 31.4% of the total variance (Figure 6). PC1 showed a strong positive correlation with fruit size and structural traits (average fruit weight, fruit width, fruit length, number of locules, and fruit shape). In contrast, PC2 was mainly associated with quality parameters, including soluble solids content (SSC), ripe fruit colour, flesh colour, colour values, and fruit firmness. In the score plot, the genotypes were separated into four main groups. Genotypes in Region I stood out with both large fruit characteristics and, to some extent, quality parameters. Region II genotypes were primarily associated with higher SSC and ripe fruit colour, offering an advantage in terms of quality but being limited in fruit size. Region III genotypes displayed strong attributes in flesh colour and colour values, while showing lower performance in yield-related traits. Region IV genotypes differentiated mainly by plant growth, leaf structure, and yield-related characteristics, but lagged behind in terms of quality traits. These results demonstrate that PCA effectively revealed clear differences among tomato genotypes based on both morphological and quality-related traits. Thus, it provides valuable insights for the selection of genotypes with high market value as well as those that can be used in breeding programs focusing on either quality or yield attributes. In a study with tomato breeding lines, it was reported that six principal component axes were independent from each other in terms of 17 traits, and these axes explained 63.35% of the total variation (Jin et al., 2019). Many studies have been reported to determine the level of variation in populations of *S. lycopersicum* L. species (Ali et al., 2016; Ali et al., 2017; Islam et al., 2022; Öztürk, 2022; Kıymacı et al., 2024). The results obtained in our study provide useful information about the tomato population's genetics. It is thought that the PCA is an important step in understanding genetic diversity and relationships among tomato genotypes, and that it will play an important role in plant breeding and genetic studies. Overall, the score plot and loading plot effectively illustrates the morphological diversity among genotypes and can guide breeders in selecting individuals with desired trait combinations based on their PCA positioning (Figure 6).

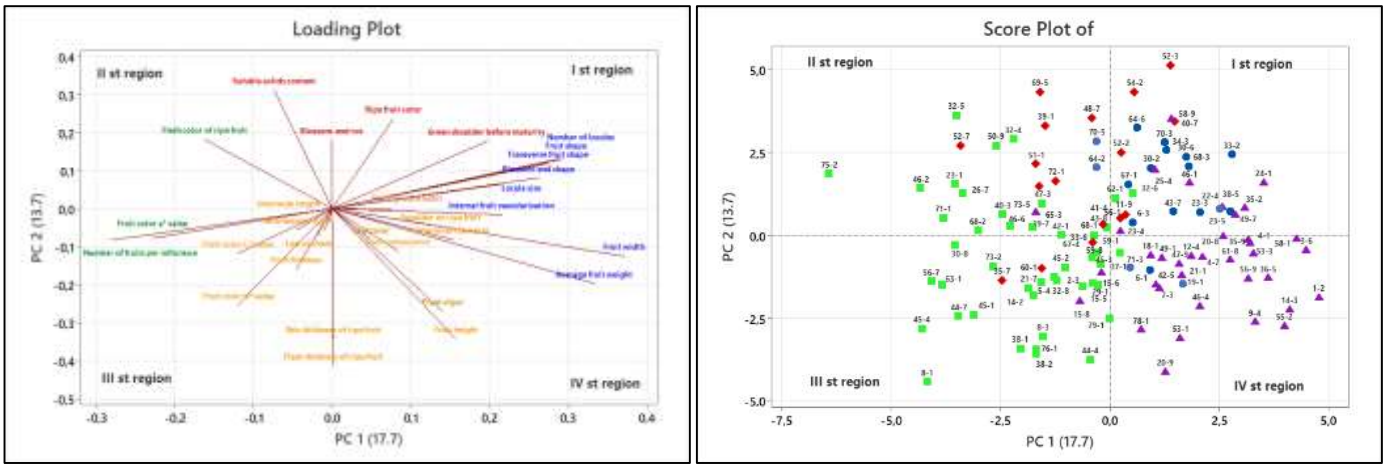


Figure 6. Loading and score plots of PCA based on morphological and quality traits of tomato genotypes.
*Şekil 6. Domates genotiplerinin morfolojik ve kalite özelliklerine dayalı PCA yükleme ve skor grafikleri.*

## Clustering Heatmap Analysis

Clustering heat map analysis, based on the standardized (Z-score) values of morphological and fruit-related traits, separated the genotypes into four main groups (Figure 7, Figure 8, and Figure 9). Group 1 was characterized mainly by small fruit shape, low locule number, low average fruit weight, and narrow fruit width. These features indicate a small and simple fruit structure. However, these genotypes exhibited relatively higher fruit firmness and fruit colour (b value*), suggesting a longer shelf-life potential, but with limited attractiveness from a market perspective. Group 2 stood out with vigorous plant growth, dense stem pubescence, and wider fruits. In addition, a pronounced shoulder structure was observed in ripe fruits. However, the soluble solids content (sugar) of the genotypes in this group was found to be low. Therefore, while yield potential is high, the internal quality, particularly sweetness, remains limited. Group 3 consisted of genotypes distinguished by high fruit quality. This group showed markedly higher flesh colour intensity, fruit firmness, soluble solids content, and the a value* (representing redness). These traits indicate strong consumer preference, nutritional value, and market suitability. Thus, Group 3 is considered the most commercially advantageous cluster. Group 4 exhibited intense red fruit colour (ripe fruit colour), but was marked by low fruit firmness, small fruit size, and susceptibility to blossom-end rot. Therefore, although the external appearance is appealing, the market value remains limited. Overall, the results revealed clear differentiation among genotype groups. Group 3 excelled in fruit quality, Group 2 in vegetative vigor

| Traits | 1 | 2 | 3 | 4 | Group 1 | | Group 2 | | Group 3 | Group 4 |
|---|---|---|---|---|---|---|---|---|---|---|
| Fruit shape | -0,74 | 0,67 | 0,46 | 0,10 | 2-3 | 46-2 | 1-2 | 55-2 | 6-1 | 11-9 |
| Blossom-end shape | -0,44 | 0,42 | 0,60 | -0,35 | 5-4 | 46-6 | 3-6 | 56-9 | 6-3 | 35-7 |
| Transverse fruit shape | -0,60 | 0,50 | 0,63 | -0,13 | 8-1 | 47-3 | 4-1 | 58-1 | 19-1 | 39-1 |
| Number of locules | -0,67 | 0,46 | 0,43 | 0,41 | 8-3 | 50-9 | 4-7 | 61-8 | 22-4 | 48-7 |
| Locule size | -0,64 | 0,47 | 0,65 | 0,06 | 14-2 | 56-7 | 7-3 | 65-3 | 23-3 | 51-1 |
| Internal fruit vascularization | -0,45 | 0,19 | 0,97 | -0,22 | 15-5 | 62-1 | 9-4 | 78-1 | 30-2 | 52-2 |
| Average fruit weight | -0,55 | 1,03 | -0,20 | -0,52 | 19-7 | 63-1 | 12-4 | | 30-6 | 52-3 |
| Fruit width | -0,65 | 0,95 | 0,15 | -0,43 | 21-7 | 67-4 | 14-3 | | 33-2 | 52-7 |
| Plant growth habit | -0,09 | 0,21 | -0,09 | -0,09 | 23-1 | 68-1 | 15-6 | | 34-3 | 54-2 |
| Plant vigor | 0,05 | 0,47 | -0,13 | -1,06 | 26-7 | 68-2 | 15-8 | | 42-5 | 56-1 |
| Stem pubescence | -0,27 | 0,33 | -0,31 | 0,40 | 29-1 | 71-1 | 18-1 | | 43-7 | 58-9 |
| Leaf attitude | 0,30 | 0,07 | 0,36 | -1,42 | 30-8 | 73-2 | 20-8 | | 64-2 | 59-1 |
| Leaf color | 0,21 | 0,21 | 0,21 | -1,33 | 32-4 | 73-5 | 20-9 | | 64-6 | 59-8 |
| Internode length | 0,03 | 0,10 | -0,21 | -0,06 | 32-5 | 75-2 | 21-1 | | 67-1 | 60-1 |
| Internode diameter | -0,22 | 0,53 | -0,25 | -0,30 | 32-6 | 76-1 | 23-4 | | 68-3 | 69-5 |
| Inflorescence type | 0,27 | -0,18 | -0,18 | -0,18 | 32-8 | 79-1 | 23-5 | | 70-3 | 72-1 |
| Shoulder on ripe fruit | -0,27 | 0,60 | -0,27 | -0,27 | 33-6 | | 24-1 | | 70-5 | |
| Fruit height | -0,09 | 0,60 | -0,42 | -0,61 | 37-1 | | 25-4 | | 71-3 | |
| Flesh thickness of ripe fruit | 0,28 | 0,22 | -0,48 | -0,76 | 38-1 | | 35-2 | | | |
| Skin thickness of ripe fruit | 0,10 | 0,14 | -0,33 | -0,24 | 38-2 | | 35-9 | | | |
| Fruit color L* value | 0,22 | -0,22 | 0,18 | -0,32 | 40-3 | | 36-5 | | | |
| Fruit color b* value | 0,23 | -0,17 | 0,12 | -0,41 | 41-4 | | 38-5 | | | |
| Fruit firmness | 0,16 | -0,35 | 0,79 | -0,56 | 42-1 | | 40-7 | | | |
| Number of fruits per inflorescence | 0,58 | -0,48 | -0,37 | -0,18 | 43-8 | | 46-1 | | | |
| Flesh color of ripe fruit | 0,18 | -0,25 | -0,69 | 0,82 | 44-4 | | 46-4 | | | |
| Fruit color a* value | 0,46 | -0,32 | -0,50 | -0,04 | 44-7 | | 47-9 | | | |
| Green shoulder before maturity | -0,51 | 0,41 | 0,52 | -0,03 | 45-1 | | 49-1 | | | |
| Ripe fruit color | -0,33 | -0,22 | 0,76 | 0,60 | 45-2 | | 49-7 | | | |
| Blossom-end rot | -0,23 | -0,36 | 1,06 | 0,28 | 45-3 | | 53-1 | | | |
| Soluble solids content | 0,02 | -0,32 | 0,47 | 0,15 | 45-4 | | 53-3 | | | |

Figure 7. Cluster distribution of tomato genotypes based on morphological and fruit quality parameters.
*Şekil 7. Domates genotiplerinin morfolojik ve kalite parametrelerine göre gruplandırılması.*

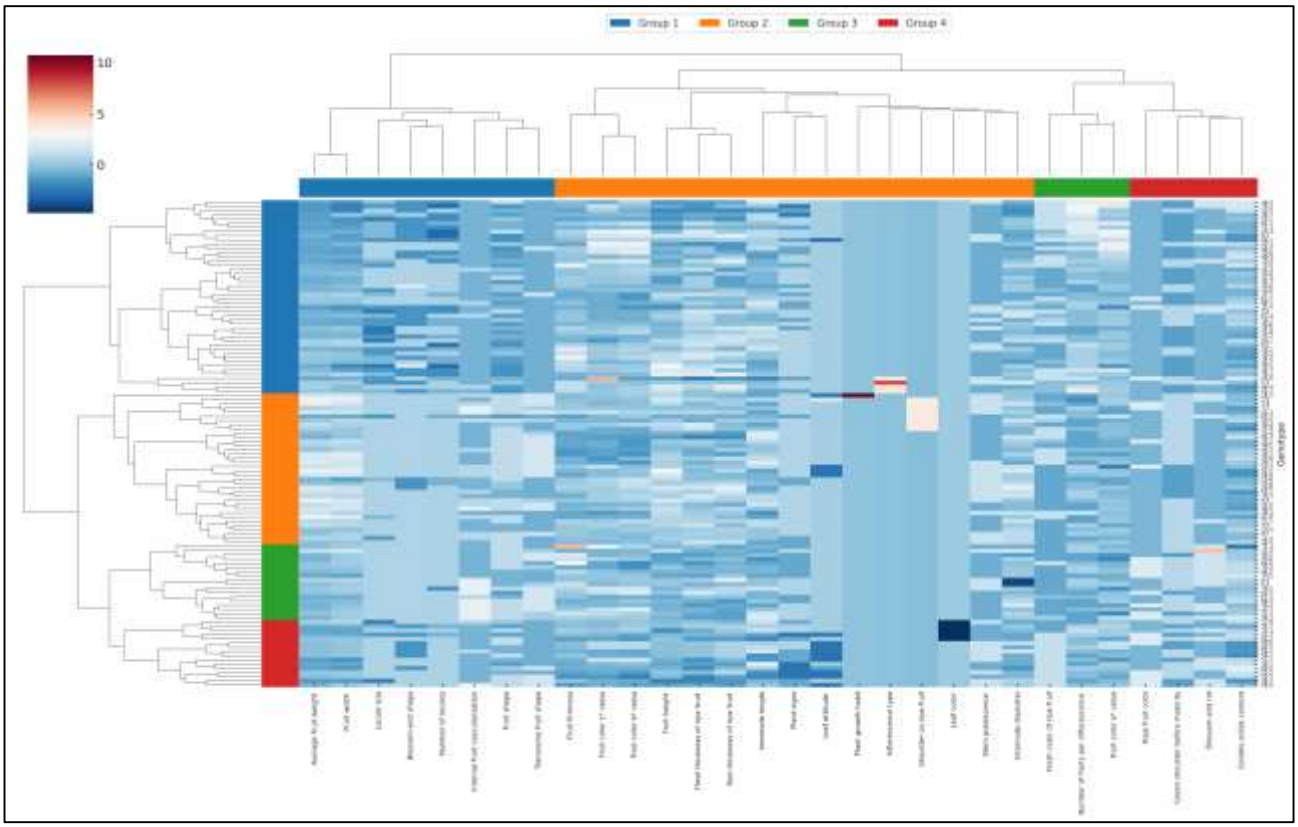


Figure 8. Clustering heatmap of tomato genotypes based on morphological and fruit traits.
*Şekil 8. Domates genotiplerinin morfolojik ve meyve özelliklerine göre kümeleme ısı haritası.*

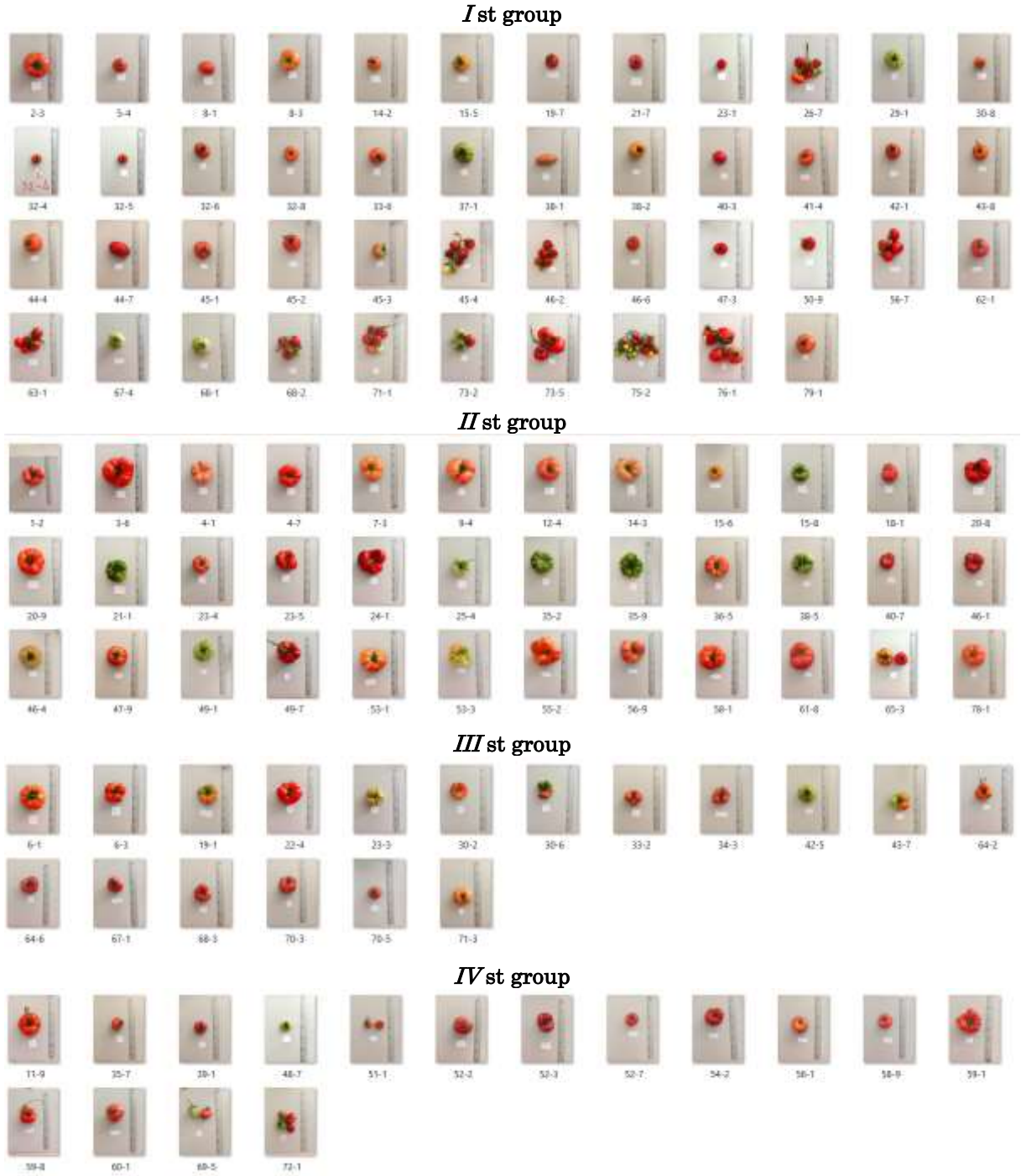


Figure 9. Fruit characteristics of tomato genotypes according to PCA plot regions.
*Şekil 9. PCA plot bölgelerine göre domates genotiplerinin meyve özellikleri.*

and yield potential, Group 1 in firmness but with small fruit structure, and Group 4 in colour advantage but with lower quality. Ali et al. (2017) reported that twelve clusters were formed as a result of cluster analysis and the genetic diversity shown by cluster analysis indicates the usefulness of germplasm for tomato hybridisation and breeding. Several studies in tomato have identified distinctive groups within genetic accessions based on similarity dendrograms between accessions (Terzopoulos & Bebeli, 2010; Grozeva et al., 2020; Rasul et al., 2022). According to these results, it was possible to evaluate the variation observed among the tomato genotypes, to group the genotypes, and to guide future breeding programs. When evaluated with the reported literature data, it is concluded that the richness of variation is at a sufficient level. In addition, dendrograms from such analyses will help with plant breeding and conservation. They'll provide valuable info to boost genetic diversity and structure breeding programs (Şavkan et al., 2024; Şavkan et al., 2025a).

## Correlation Matrix

The correlation matrix revealed strong positive relationships among fruit yield and size-related traits. Average fruit weight (Afw) showed a very strong positive correlation with fruit width (Fw, r=0.91). Similarly, Afw was positively correlated with fruit height (Fh, r=0.53) and fruit thickness (Ft, r=0.56). These findings indicate that fruit weight is directly influenced by both longitudinal and transverse fruit development. Other yield-related traits also exhibited similar trends. Fruit width (Fw) was positively correlated with the number of locules (Nol, r=0.48) and total seed number (Tfs, r=0.52). This result suggests that locule and seed development play an important role in increasing fruit size and, consequently, fruit yield. In contrast, quality-related traits generally showed negative correlations with yield components. Soluble solids content (SSC) was negatively correlated with fruit width (Fw, r=-0.42), fruit thickness (Ft, r=-0.46), and number of locules (Nol, r=-0.31). This indicates that larger and more locule-rich fruits may have lower soluble solids content, reflecting a trade-off between yield and fruit quality. Regarding colour parameters, the a* value (redness) was positively correlated with the number of locules (Nol, r=0.42), but negatively correlated with fruit width (Fw, r=-0.33). This suggests that redder fruits may be associated with higher locule numbers but smaller fruit size. The b* value (yellowness) showed a positive correlation with L* (lightness, r=0.66) and fruit thickness (Ft, r=0.23). Among vegetative traits, leaf area (La) was positively correlated

with plant height (Pv, r=0.26), while showing a negative correlation with plant growth habit (Pgh, r=-0.25). Overall, the correlation analysis highlights a clear trade-off between yield and quality traits in tomato genotypes. While larger fruits with more locules tend to increase yield, they are often associated with reduced quality parameters such as soluble solids content. These findings underline the importance of balancing both yield and quality targets in breeding programs (Table 5).

*Table 5. Correlation matrix of morphological and fruit quality traits in tomato genotypes*
*Çizelge 5. Domates genotiplerinde morfolojik ve meyve kalite özellikleri arasındaki korelasyon matrisi*

| | Pgh | Pv | Sp | La | Lc | Il | Id | It | Nfi | Gsm | Fs | Rfc | Srf | Ber | Bes | Fcrf | Tfs | Nol | Ls | Ifv | Afw | Fw | Fh | Ft | St | L* | a* | b* | Ssc | Ff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pgh | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pv | 0,07 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sp | 0,12 | 0,03 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| La | -0,25 | 0,26 | -0,34 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lc | 0,02 | 0,13 | 0,08 | 0,05 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Il | -0,10 | 0,21 | 0,02 | 0,16 | 0,00 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | | |
| Id | 0,00 | 0,23 | 0,14 | -0,02 | 0,12 | -0,03 | 1,00 | | | | | | | | | | | | | | | | | | | | | | | |
| It | -0,02 | 0,01 | 0,08 | 0,06 | 0,04 | -0,13 | 0,10 | 1,00 | | | | | | | | | | | | | | | | | | | | | | |
| Nfi | -0,10 | -0,11 | -0,02 | -0,01 | -0,04 | -0,05 | -0,29 | 0,20 | 1,00 | | | | | | | | | | | | | | | | | | | | | |
| Gsm | 0,08 | -0,02 | 0,01 | 0,16 | -0,01 | -0,07 | 0,07 | 0,01 | -0,37 | 1,00 | | | | | | | | | | | | | | | | | | | | |
| Fs | 0,10 | 0,18 | 0,19 | -0,07 | 0,02 | 0,03 | 0,27 | -0,12 | -0,45 | 0,44 | 1,00 | | | | | | | | | | | | | | | | | | | |
| Rfc | -0,05 | -0,23 | 0,02 | -0,21 | -0,11 | -0,20 | 0,08 | 0,00 | -0,16 | 0,08 | 0,21 | 1,00 | | | | | | | | | | | | | | | | | | |
| Srf | -0,03 | 0,13 | 0,07 | 0,15 | 0,06 | -0,09 | 0,09 | -0,05 | -0,18 | 0,23 | 0,17 | 0,04 | 1,00 | | | | | | | | | | | | | | | | | |
| Ber | 0,13 | -0,13 | 0,05 | 0,06 | -0,04 | -0,06 | -0,10 | 0,04 | 0,00 | 0,25 | 0,24 | 0,18 | -0,02 | 1,00 | | | | | | | | | | | | | | | | |
| Bes | 0,06 | 0,09 | -0,12 | 0,15 | 0,06 | -0,03 | 0,03 | -0,13 | -0,40 | 0,30 | 0,29 | 0,16 | 0,16 | 0,09 | 1,00 | | | | | | | | | | | | | | | |
| Fcrf | -0,09 | -0,26 | -0,10 | -0,25 | 0,01 | -0,01 | -0,15 | 0,01 | 0,20 | -0,03 | -0,14 | 0,07 | -0,03 | -0,05 | -0,30 | 1,00 | | | | | | | | | | | | | | |
| Tfs | 0,15 | 0,08 | 0,03 | -0,10 | 0,15 | 0,07 | 0,10 | -0,12 | -0,36 | 0,22 | 0,52 | 0,19 | 0,12 | 0,06 | 0,37 | -0,13 | 1,00 | | | | | | | | | | | | | |
| Nol | 0,05 | 0,06 | -0,01 | -0,11 | -0,02 | -0,08 | 0,21 | 0,02 | -0,53 | 0,39 | 0,41 | 0,18 | 0,11 | 0,02 | 0,49 | -0,18 | 0,32 | 1,00 | | | | | | | | | | | | |
| Ls | 0,06 | 0,10 | -0,04 | -0,13 | 0,13 | -0,06 | 0,00 | -0,14 | -0,14 | 0,19 | 0,35 | 0,12 | 0,10 | 0,07 | 0,30 | -0,19 | 0,37 | 0,44 | 1,00 | | | | | | | | | | | |
| Ifv | 0,08 | 0,22 | 0,16 | -0,06 | 0,06 | 0,07 | 0,03 | -0,05 | -0,21 | 0,16 | 0,29 | 0,15 | 0,14 | -0,01 | 0,29 | -0,31 | 0,46 | 0,27 | 0,28 | 1,00 | | | | | | | | | | |
| Afw | 0,15 | 0,39 | 0,30 | 0,00 | 0,08 | 0,00 | 0,27 | 0,01 | -0,32 | 0,21 | 0,36 | -0,07 | 0,30 | -0,14 | 0,34 | -0,28 | 0,35 | 0,38 | 0,30 | 0,26 | 1,00 | | | | | | | | | |
| Fw | 0,15 | 0,37 | 0,24 | -0,04 | 0,08 | 0,06 | 0,27 | -0,02 | -0,43 | 0,26 | 0,47 | 0,02 | 0,23 | -0,09 | 0,45 | -0,30 | 0,47 | 0,48 | 0,41 | 0,36 | 0,91 | 1,00 | | | | | | | | |
| Fh | 0,08 | 0,38 | 0,17 | -0,04 | 0,12 | -0,11 | 0,19 | 0,10 | -0,06 | -0,12 | -0,05 | -0,22 | 0,14 | -0,26 | 0,08 | -0,25 | 0,06 | 0,01 | 0,06 | 0,10 | 0,69 | 0,53 | 1,00 | | | | | | | |
| Ft | -0,01 | 0,40 | 0,08 | 0,19 | 0,09 | 0,09 | 0,15 | -0,03 | 0,06 | -0,19 | -0,27 | -0,35 | 0,10 | -0,34 | -0,13 | -0,30 | -0,25 | -0,22 | -0,13 | -0,03 | 0,30 | 0,19 | 0,56 | 1,00 | | | | | | |
| St | -0,05 | 0,26 | 0,24 | -0,01 | 0,05 | -0,01 | 0,09 | 0,08 | 0,07 | -0,18 | -0,26 | -0,23 | 0,00 | -0,20 | -0,13 | -0,14 | -0,22 | -0,19 | -0,12 | -0,01 | 0,29 | 0,18 | 0,54 | 0,63 | 1,00 | | | | | |
| L* | 0,00 | 0,03 | 0,11 | 0,01 | 0,09 | -0,05 | -0,07 | 0,21 | 0,25 | -0,15 | -0,13 | 0,01 | -0,02 | 0,05 | -0,06 | -0,19 | -0,16 | -0,24 | -0,02 | 0,04 | -0,18 | -0,20 | -0,07 | 0,04 | 0,01 | 1,00 | | | | |
| a* | 0,00 | 0,04 | -0,07 | 0,06 | -0,02 | 0,18 | -0,21 | 0,02 | 0,42 | -0,22 | -0,28 | -0,29 | -0,05 | 0,08 | -0,38 | 0,30 | -0,24 | -0,35 | -0,12 | -0,20 | -0,25 | -0,33 | -0,07 | 0,09 | -0,01 | 0,20 | 1,00 | | | |
| b* | 0,03 | 0,25 | 0,05 | 0,09 | 0,07 | 0,12 | -0,04 | -0,02 | 0,17 | -0,31 | -0,20 | -0,31 | -0,01 | 0,05 | -0,14 | -0,33 | -0,20 | -0,24 | 0,03 | 0,09 | -0,14 | -0,19 | 0,06 | 0,33 | 0,23 | 0,66 | 0,42 | 1,00 | | |
| Ssc | -0,03 | -0,37 | -0,23 | 0,12 | -0,12 | -0,06 | -0,13 | -0,04 | -0,03 | 0,27 | -0,07 | 0,22 | -0,14 | 0,28 | 0,04 | 0,23 | 0,00 | 0,03 | 0,06 | -0,09 | -0,31 | -0,27 | -0,42 | -0,46 | -0,29 | -0,09 | 0,05 | -0,20 | 1,00 | |
| Ff | -0,04 | 0,06 | -0,05 | 0,22 | 0,06 | -0,04 | -0,06 | 0,13 | 0,09 | -0,07 | -0,07 | -0,06 | -0,02 | 0,08 | -0,01 | -0,33 | -0,19 | -0,04 | -0,06 | 0,00 | -0,07 | -0,06 | 0,07 | 0,24 | 0,14 | 0,31 | -0,04 | 0,34 | -0,23 | 1,00 |

The traits and their corresponding abbreviations are as follows: plant growth habit (Pgh), plant vigor (Pv), stem pubescence (Sp), leaf attitude (La), leaf colour (Lc), internode length (Il), internode diameter (Id), and inflorescence type (It). Reproductive and fruit-related traits included the number of fruits per inflorescence (Nfi), green shoulder before maturity (Gsm), fruit shape (Fs), ripe fruit colour (Rfc), shoulder on ripe fruit (Srf), blossom-end rot (Ber), blossom-end shape (Bes), and flesh colour of ripe fruit (Fcrf). In addition, traits such as transverse fruit shape (Tfs), number of locules (Nol), locule size (Ls), and internal fruit vascularization (Ifv) were examined. Yield-related

parameters included average fruit weight (Afw), fruit width (Fw), fruit height (Fh), flesh thickness of ripe fruit (Ft), and skin thickness of ripe fruit (St). Furthermore, fruit colour parameters were measured as L (lightness), *a (green-red scale), and b (blue-yellow scale) values. Finally, fruit quality traits such as soluble solids content (Ssc) and fruit firmness (Ff) were recorded (Table 5).

## CONCLUSION

In this study, 116 tomato genotypes collected from Central Anatolia were evaluated for morphological and quality traits, and their variation was revealed through PCA, clustering, and correlation analyses. The genotypes were grouped into four main clusters, with Group 3 showing the highest market value due to its superior SSC, firmness, and colour intensity. Correlation analysis highlighted a clear trade-off between yield and quality traits. Overall, the findings provide valuable insights for tomato breeding programs, particularly in selecting genotypes that combine both high yield and quality. However, the lack of molecular data remains a limitation of the study, and future research integrating molecular markers will be essential to assess genetic diversity and support breeding strategies more comprehensively.

## ACKNOWLEDGMENTS

We thank all staff members of the To Geothermal Advanced Greenhouse Technologies and Production Techniques Co-Application and Research Center (JISTUAM) of Kırşehir Ahi Evran University for the technical support and for supplying all facilities during the experiments.

### Contribution Rate Statement Summary of Researchers

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

### Conflict of Interest

The authors declares that he has no known competing financial interests or personal relationships that could influence the work in this article.

## REFERENCES

Agong, S.G., Schittenhelm, S., & Friedt, W. (2001). Genotypic variation of Kenyan tomato (*Lycopersicon esculentum* L.) germplasm. *Plant Genetic Resources Newsletter, 123*, 61–67. https://doi.org/10.4314/jfta.v6i1.19277

Ali, A., Hussain, I., Khan, A., Khan, J., ... & Rehman, M.U. (2016). Evaluation of various tomato (*Lycopersicon esculentum* Mill.) cultivars for quality, yield and yield component under agro-climatic condition of Peshawar. *ARPN Journal of Agriculture and Biological Sciences, 11,* 59–62.

Ali, Q., Erkan, M., & Jan, I. (2017). Morphological and agronomic characterization of tomato under field conditions. *Pure and Applied Biology (PAB), 6*(3), 1021-1029. http://dx.doi.org/10.19045/bspab.2017.600108

Aybak HÇ. 2015. Serada ve açık alanda domates yetiştiriciliği. *Hasad Yayıncılık*, İstanbul. ISBN: 978-975-8377-24-4.

Aydın, A. (2024a). The growth, leaf antioxidant enzymes and amino acid content of tomato as affected by grafting on wild tomato rootstocks 1 (*S. pimpinellifolium* and *S. habrochaites*) under salt stress. *Scientia Horticulturae, 325*, 112679. https://doi.org/10.1016/j.scienta.2023.112679

Aydin, A. (2024b). Effects of grafting with wild tomato (*Solanum pimpinellifolium* and *Solanum habrochaites*) rootstocks on growth and leaf mineral accumulation in salt stress. *Horticulture, Environment, and Biotechnology, 65*(5), 785-801. https://doi.org/10.1007/s13580-024-00607-5

Aydın, A., & Başak, H. (2024). Morphological and pomological characterization of F2 generation cucumber (*Cucumis sativus* L.) plants of different fruit types. *International Journal of Agriculture Environment and Food Sciences, 8*(4), 932-943. https://doi.org/10.31015/jaefs.2024.4.23

Aydin, A., & Yetişir, H. (2023). A comparative study of morphological characteristics in diploid and tetraploid (auto and allotetraploids) Citrullus genotypes. *Folia Horticulturae, 35*(1), 33-48. https://doi.org/10.2478/fhort-2023-0003

Aydın, A., Başak, H., Aydın, H., & Güngör, R. (2024). Characterization of F2 generation tomato plants and marker assisted selection against *Tomato spotted wilt virus* (tswv) and *Tomato yellow leaf curl virus* (tylcv). International Journal of Agriculture Environment and Food Sciences, *8*(3), 618-628. https://doi.org/10.31015/jaefs.2024.3.15

Bajracharya, J., Steele, K., Jarvis, D., Sthapit, B., Witcombe, J. (2006). Rice landrace diversity in nepal: Variability of agro-morphological traits and ssr markers in landraces from a high-altitude site. *Field Crops Research, 95* (2-3), 327-335. https://doi.org/10.1016/j.fcr.2005.04.014

Başak, H., Aydin, A., Aydin, H., & Turan, M. (2025 b). Phytochemical profile analysis of tomato cultivars based on color and size. *Journal of Food Composition and Analysis*, *146*, 107992. https://doi.org/10.1016/j.jfca.2025.107992

Başak, H., Aydin, A., Yetisir, H., & Turan, M. (2025a). Salt stress effects on hybrid bottle gourd (*Lagenaria siceraria*) rootstock candidates plant growth, hormones and nutrient content. *Journal of Crop Health, 77*, 28. https://doi.org/10.1007/s10343-024-01087-4

Bernousi, I., Emami, A., Tajbakhsh, M., Darvishzadeh, R., Henareh, M. (2011). Studies on genetic variability and correlation among the different traits in *Solanum lycopersicum* L. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 39*, 152–158. https://doi.org/10.15835/nbha3915859

Bhattarai, K., Louws, F.J., Williamson, J.D., Panthee, D.R. (2016). Diversity analysis of tomato genotypes based on morphological traits with commercial breeding significance for fresh market production In Eastern USA. *Australian Journal of Crop Science, 10*(8), 1098-1103. DOI: 10.21475/ajcs.2016.10.08.p7391

Bhattarai, K., Sharma, S., & Panthee, D.R. (2018). Diversity among modern tomato genotypes at different levels in fresh-market breeding. *International Journal of Agronomy, 2018*(1), 4170432. https://doi.org/10.1155/2018/4170432

Çukadar, K. (2011). *Erzincan İli Domates (Lycopersicon esculentum L.) Genotiplerinin Morfolojik Karakterizasyonu* (Tez no 284383) [Yüksek Lisans Tezi, Atatürk Üniversitesi Fen Bilimleri Enstitüsü Bahçe Bitkileri Anabilim Dalı]. Yükseköğretim Kurulu Ulusal Tez Merkezi.

Demir, Ö., & Ünlü, H. (2023). Bazı beef tipi domates hatlarının morfolojik özelliklerinin belirlenmesi. *Ziraat Fakültesi Dergisi, 18*(1), 59-65. https://doi.org/https://doi.org/10.54975/isubuzfd.1288727

Dharmatti, P., Madalgeri, B., Mannikeri, I., Patil, R., Patil, G. (2001). Genetic divergence studies in summer tomatoes. *Karnataka Journal of Agricultural Sciences, 14* (2): 407-411.

Fao, 2025. FAO Statistical Database. http://faostat3.fao.org/browse/Q/QC/E. (Erişim Tarihi: 22.03.2025).

Figàs, M., Prohens, J., Raigón, M., Fita, A., García-Martínez, M., Casanova, C., ... & Soler, S. (2015). Characterization of composition traits related to organoleptic and functional quality for the differentiation, selection and enhancement of local varieties of tomato from different cultivar groups. *Food Chemistry, 187,* 517-524. https://doi.org/10.1016/j.foodchem.2015.04.083

Fiorani, F., & Schurr, U. (2013). Future scenarios for plant phenotyping. *Annual Review Of Plant Biology, 64*(1), 267-291. https://doi.org/10.1146/annurev-arplant-050312-120137

Gerrano, A.S., Adebola, P.O., van Rensburg, W.S.J., Laurie, S.M. (2015). Genetic variability in cowpea (*Vigna unguiculata* L. Walp.) genotypes. *South African Journal of Plant and Soil, 32*, 165–174. https://doi.org/10.1080/02571862.2015.1014435

Grozeva, S., Nankar, A.N., Ganeva, D., Tringovska, I., Pasev, G., & Kostova, D. (2020). Characterization of tomato accessions for morphological, agronomic, fruit quality, and virus resistance traits. *Canadian Journal of Plant Science, 101*(4), 476-489. https://doi.org/10.1139/cjps-2020-0030

Güngör, R., Başak, H., & Aydın, A. (2023). S2 kademesindeki domates genotiplerinin morfolojik ve pomolojik karakterizasyonu. *Kırşehir Ahi Evran Üniversitesi Ziraat Fakültesi Dergisi, 3*(2), 152-163.

Hernández-Villareal, A.E. 2013. Caracterización morfológica de recursos fitogenéticos. *Revista BioCiencias: 2*(3), 113-118. https://doi.org/10.15741/revbio.02.03.05

Heuvelink, E., & Körner, O. (2001). Parthenocarpic fruit growth reduces yield fluctuation and blossom-end rot in sweet pepper. *Annals of Botany, 88*(1), 69-74. https://doi.org/10.1006/anbo.2001.1427

Ho, L.C., & White, P.J. (2005). A cellular hypothesis for the induction of blossom-end rot in tomato fruit. *Annals of Botany, 95*(4), 571-581. https://doi.org/10.1093/aob/mci065

Islam, S., Hassan, L., & Hossain, M. (2022). Breeding potential of some exotic tomato lines: a combined study of morphological variability, genetic divergence, and association of traits. *Phyton, 91*(1), 97-114. https://doi.org/10.32604/phyton.2022.017251

Jin, L., Zhao, L., Wang, Y., Zhou, R., Song, L., Xu, L., Cui, X., Li, R., Yu, W., Zhao, T. (2019). Genetic diversity of cultivated tomato germplasm resources using agronomic traits and indel markers. *Euphytica, 215*, 69. https://doi.org/10.1007/s10681-019-2391-8

Kıymacı, G., Uncu, A.Ö, Türkmen, Ö. (2024). Description of the phenotypic characteristics of some tomato genotypes. *Selcuk Journal of Agriculture and Food Sciences 38* (1), 9-26. https://doi.org//selcukjafsci.1299209

Kouam, E., Dongmo, J., & Djeugap, J. (2018). Exploring morphological variation in tomato (*Solanum lycopersicum*): A combined study of disease resistance, genetic divergence and association of characters. *Agricultura Tropica Et Subtropica, 51*(2), 71-82. https://doi.org/10.1515/ats-2018-0008

Marcelis, L.F.M., & Ho, L.C. (1999). Blossom-end rot in relation to growth rate and calcium content in fruits of sweet pepper (*Capsicum annuum* L.). *Journal of Experimental Botany, 50*(332), 357-363. https://doi.org/10.1093/jxb/50.332.357

Minitab, (2016). Minitab Statistics Software (16.00) for Cluster and Principal Component Analysis (PCA). http://www.minitab.com. Accessed 25 March 25.

Mitul, R., Haque, M., Rima, S., & Begum, S. (2016). Field performance and genetic analysis of selected tomato (*Lycopersicon esculentum* mill.) genotypes. *Journal of the Bangladesh Agricultural University, 14*(1), 31-36. https://doi.org/10.3329/jbau.v14i1.30593

Oduor, K.T. (2016). Agro-morphologıcal and Nutrıtıonal Characterızatıon of Tomato Landraces (*Lycopersicon* species) in Africa. (Doctoral Dissertation), Unıversıty of Nairobi, Kenya.

Oğuz, A. (2010). *Bazı Yerel Domates Genotiplerinde Farklı Yöntemler Kullanarak, Domates Lekeli Solgunluk Virüsü (Tomato Spotted Wilt Virüs= TSWV)'ne Dayanıklılığın ve Genetik Varyasyonun Araştırılması* [Doktora Tezi, Ankara Üniversitesi, Fen Bilimleri Enstitusü, Bahçe Bitkileri Ana Bilim Dalı]. Yükseköğretim Kurulu Ulusal Tez Merkezi.

Öztürk, H. (2022). Morphological and molecular characterization of some tomato (*Solanum lycopersicum* l.) genotypes collected from Erzincan province of Turkey. *Molecular Biology Reports, 49*(7), 7111-7121. https://doi.org/10.1007/s11033-022-07310-7

Paiva, É.A.S., Figueredo, C.C., & Martinez, H.E.P. (2023). Vascular tissues distribution affects calcium and calcium oxalate crystals in fruits of wild tomato (*Lycopersicon pimpinellifolium* (L.) Mill.). *Plants, 12*(22), 3893. https://doi.org/10.3390/plants12223893

Peralta, I.E., Knapp, S., & Spooner, D.M. (2005). New species of wild tomatoes (*Solanum* section *Lycopersicon*: *Solanaceae*) from Northern Peru. *Systematic Botany, 30*(2), 424-434. https://doi.org/10.1600/0363644054223657

Peralta, I.E., Spooner, D.M., & Knapp, S. (2008). Taxonomy of wild tomatoes and their relatives (*Solanum* sect. *Lycopersicoides,* sect. *Juglandifolia*, sect. *Lycopersicon*; *Solanaceae*). *Am. Soc. Plant Taxonomists, 2008*, 151-160. https://www.jstor.org/stable/25027972

Rahmadian, F., Yunandra, Y., Zuhry, E., Irfandri, I., Saputra, R., Masruri, N.W., ... & Destiani, E. (2024). Characterization and genetic relationship of several tomato (*Solanum lycopersicum* L.) genotypes from various regions. *Jurnal Agronomı Tanaman Tropıka (JUATIKA), 6*(2), 208-223. https://doi.org/10.36378/juatika.v6i2.3579

Rasul, K.S., Grundler, F.M.W. & Abdul-razzak Tahir, N. (2022). Genetic diversity and population structure assessment of iraqi tomato accessions using fruit characteristics and molecular markers. *Hortic. Environ. Biotechnol. 63*, 523–538. https://doi.org/10.1007/s13580-022-00429-3

Renna, M., D'Imperio, M., Gonnella, M., Durante, M., Parente, A., Mita, G., Santamaria, P., & Serio, F. (2019). Morphological and chemical profile of three tomato (*solanum lycopersicum* l.) landraces of a semi-arid mediterranean environment. *Plants, 8*(8), 273. https://doi.org/10.3390/plants8080273

Sacco, A., Ruggieri, V., Parisi, M., Festa, G., Rigano, M.M., Picarella, M.E., ... & Barone, A. (2015). Exploring a tomato landraces collection for fruit-related traits by the aid of a high-throughput genomic platform. *PLoS One, 10*(9), e0137139. https://doi.org/10.1371/journal.pone.0137139

Saka, A. (2023). *Orta ve Doğu Karadeniz Bölgesinden Toplanan Bazı Yerel Domates Popülasyonlarının Karakterizasyonu ve Biyokimyasal İçeriklerinin Belirlenmesi.* (Tez No: 777493), [Doktora Tezi, Ordu Üniversitesi, Fen Bilimleri Enstitüsü, Bahçe Bitkileri Ana Bilim Dalı]. Yükseköğretim Kurulu Ulusal Tez Merkezi.

Salim, M.M.R., Rashid, M.H., Hossain, M.M., & Zakaria, M. (2020). Morphological characterization of tomato (*Solanum lycopersicum* L.) genotypes. *Journal of the Saudi Society of Agricultural Sciences, 19*(3), 233-240. https://doi.org/10.1016/j.jssas.2018.11.001

SPSS, (2013). IBM SPSS Statistics 21.0 for Windows. Armonk, NY.

Şavkan, A.N., & Türkmen, Ö. (2023). Morphological characterization and selection in some summer squash (*Cucurbita pepo* L.) genotypes. *Yuzuncu Yıl University Journal of Agricultural Sciences, 33*(4), 665-674. https://doi.org/10.29133/yyutbd.1332485

Şavkan, A.N., Başak, H., & Türkmen, Ö. (2024). Morphological characterization of some capia pepper (*Capsicum annuum* L.) genotypes. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 27*(6), 1332-1342. https://doi.org/10.18016/ksutarimdoga.vi.1440798

Şavkan, A.N., Başak, H., Uncu, A.T., &Türkmen, Ö. (2025a). Morphological characterization and molecular marker-assisted selection for resistance to *Tobacco mosaic virus* (TMV) and *Tomato spotted wilt virus* (TSWV) in S2 population of capia pepper (*Capsicum annuum* L.). *Genet Resour Crop Evol*, *72*, 767–782. https://doi.org/10.1007/s10722-024-02013-3

Şavkan, A.N., Dal Canbar, Y., & Türkmen, Ö. (2025b). Identification and selection of genetic diversity of some selected summer squash (*Cucurbita pepo* L.). *Yuzuncu Yıl University Journal of Agricultural Sciences, 35*(1), 121-134. https://doi.org/10.29133/yyutbd.1567738

Tembe, K. O., Chemining'wa, G., Ambuko, J., & Owino, W. (2018). Evaluation of African tomato landraces (*Solanum lycopersicum*) based on morphological and horticultural traits. *Agriculture and Natural Resources, 52*(6), 536-542. https://doi.org/10.1016/j.anres.2018.11.014

Terzopoulos, P., Bebeli, P (2010). Phenotypic diversity in Greek tomato (*Solanum lycopersicum* L.) landraces. *Sci. Hort., 126*, pp. 138-144. https://doi.org/10.1016/j.scienta.2010.06.022

Turhan, A., & Şeniz, V. (2009). Türkiye'de yetiştirilen bazı domates gen kaynaklarının verim, meyve ve morfolojik özelliklerinin belirlenmesi. *Selcuk Journal of Agriculture and Food Sciences, 23*(50), 52-59. ISSN: 2458-8377

Upov, (2024). *Solanum lycopersicum* L.. Internatıonal Unıon For The Protectıon Of New Varıetıes Of Plants. https://www.upov.int/portal/index.html.en. Accessed 16 May 2024

Van Berloo, R., Zhu, A., Ursem, R., Verbakel, H., Gort, G., & van Eeuwijk, F.A. (2008). Diversity and linkage disequilibrium analysis within a selected set of cultivated tomatoes. *Theoretical and Applied Genetics, 117*, 89-101. https://doi.org/10.1007/s00122-008-0755-x

Vardanian, I., Sargsyan, G., Martirosayn, G., Pahlevanyan, A., Tsereteli, I., Martorosyan, H., ... & Harutyunyan, Z. (2025). Lycopene in tomatoes: Genetic regulation, agronomic practices, and environmental influence. *Functional Food Science*, *5*(4), 127-145. https://doi.org/10.31989/ffs.v5i4.1617

Vishwanath, K., Rajendra, P.S., Pallavi, H.M., & Prasanna, K.P.R. (2014). Characterization of Tomato Cultivars Based on Morphological Traits. *Annals of Plant Sciences, 3*(11), 854-862. http://www.annalsofplantsciences.com/

Yardım, Z., Özen, R. N., Bozaba, E., Arı, B.Ç., & Paksoy, M. (2024). Türkiye ve Kırgızistan yerel sanayilik domates genotiplerinin morfolojik ve agronomik özelliklerinin belirlenmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 27*(Ek Sayı 1 (Suppl 1), 194-204. https://doi.org/10.18016/ksutarimdoga.vi.1474041

Yaşar, A., Şavkan, A.N. & Türkmen, Ö. (2025). Agromorphological characterization and molecular evaluation of a marker associated with *Zym-1* allele resistance of local zucchini genotypes. *Euphytica, 221*(77), 1-12. https://doi.org/10.1007/s10681-025-03538-z

Yesmin, L., Islam, M.S., Rahman, M.M., Uddin, M.N., & Ahmad, S. (2014). Inbred and hybrid seed production potentiality of tomato (*Lycopersicon esculentum*) genotypes and their yield performance during summer. *Bangladesh Journal of Agricultural Research, 39*(1), 13-21. https://doi.org/10.3329/bjar.v39i1.20057

Zhang, J., Zhao, J., Liang, Y., & Zou, Z. (2015). Genome-wide association-mapping for fruit quality traits in tomato. *Euphytica, 207*(2), 439-451. https://doi.org/10.1007/s10681-015-1567-0

Zhou, R., Wu, Z., Cao, X., & Jiang, F. (2015). Genetic diversity of cultivated and wild tomatoes revealed by morphological traits and SSR markers. *Genet. Mol. Res, 14*(4), 13868-13879. http://dx.doi.org/10.4238/2015.October.29.7