Research Article

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Identification of Relationships Between Chemical and Agromorphological Traits in Raspberry (*Rubus idaeus* Linnaeus) Genotypes by Multivariate Analysis

Ahududu (*Rubus idaeus* Linnaeus) Genotiplerinde Kimyasal ve Agromorfolojik Özellikler Arasındaki İlişkilerin Multivariate Analizi ile Belirlenmesi

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Abstract: In this study, agro-morphological characteristics of raspberry (*Rubus idaeus* Linnaeus) genotypes naturally grown in Çivril, the central district of Bolu province in Türkiye were determined. In the study, parameters belonging to the genotypes were determined as follows: fruit weight was between 2.52 g (Genotype 4) and 1.30 g (Genotype 2), fruit width was between 18.18 mm (Genotype 6) and 15.33 mm (Genotype 2), fruit length was between 18.45 mm (Genotype 6) and 12.87 mm (Genotype 2), seed width was between 1.30 mm (Genotype 4) and 1.10 mm (Genotype 6), seed height was between 2.37 mm (Genotype 1) and 1.84 mm (Genotype 6). In addition, in genotypes, fruit stem thickness ranged from 0.91 mm (Genotype 4) to 0.67 mm (Genotype 5), fruit stem pit depth ranged from 13.99 mm (Genotype 6) to 10.58 mm (Genotype 5), fruit stem pit width ranged from 10.08 mm (Genotype 4) to 7.82 mm (Genotype 9). Also, genotype 3 (13.80%) had the highest soluble solids content (SSC) and Genotype 9 (3.60%) had the highest titratable acidity (TA). The pH values observed in the genotypes varied between 3.06 and 3.29. Also, in color value parameters, the highest L*, a*, b*, chroma and hue° angle values were 32.22 (Genotype 8), 23.75 (Genotype 1), 12.86 (Genotype 1), 27.10 (Genotype 1) and 28.22 (Genotype 1), respectively. As a result of the study, it was concluded that various genotypes that stand out in terms of agro-morphological characteristics can be evaluated as breeding material in functional raspberry production.

Keywords: Raspberry, morphology, soluble solids content (SSC), titratable acidity value (TA), color parameters

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Öz: Bu çalışmada, Türkiye'de Bolu ili merkez ilçesi Çivril yöresinde doğal olarak yetişen ahududu (*Rubus idaeus* Linnaeus) genotiplerine ait meyvelerin agro-morfolojik özellikleri belirlenmiştir. Çalışmada, genotiplere ait parametrelerde, meyve ağırlığı 2.52 g (Genotip 4) ile 1.30 g (Genotip 2), meyve eni 18.18 mm (Genotip 6) ile 15.33 mm (Genotip 2), meyve boyu 18.45 mm (Genotip 6) ile 12.87 mm (Genotip 2), çekirdek eni 1.30 mm (Genotip 4) ile 1.10 mm (Genotip 6), çekirdek boyu 2.37 mm (Genotip 1) ile 1.84 mm (Genotip 6) arasında saptanmıştır. Ek olarak, genotiplerde, meyve sap kalınlığı 0.91 mm (Genotip 4) - 0.67 mm (Genotip 5); meyve sap çukur derinliği 13.99 mm (Genotip 6) - 10.58 mm (Genotip 5); meyve sap çukur genişliği 10.08 mm (Genotip 4) - 7.82 mm (Genotip 9) aralığında tespit edilmiştir. Ayrıca, en yüksek çözünebilir katı madde miktarı (SÇKM) açısından Genotip 3 (% 13.80) genotipi, en yüksek titre edilebilir asitlik (TA) değeri açısından Genotip 9 (% 3.60) genotipi daha baskın olmuştur. Genotiplerde gözlenen pH değerleri ise 3.06 ile 3.29 arasında değişmiştir. Ayrıca, renk değeri parametrelerinde, en yüksek L*, a*, b*, kroma ve hue° açısı değerleri, sırasıyla, 32.22 (Genotip 8), 23.75 (Genotip 1), 12.86 (Genotip 1), 27.10 (Genotip 1) ve 28.22 (Genotip 1) olarak bulunmuştur. Çalışmada sonuç olarak, agro-morfolojik özellikler açısından öne çıkan çeşitli genotiplerin fonksiyonel ahududu üretiminde ıslah materyali olarak değerlendirilebileceği kanısına varılmıştır.

Anahtar Kelimeler: Ahududu, morfoloji, çözünebilir katı madde miktarı (SÇKM), titre edilebilir asitlik değeri (TA), renk parametreleri

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INTRODUCTION

There are 15 subgenera in the genus *Rubus* spp. of the Rosaceae family and these genera contain approximately 740 species. The most important species of this genus are *R. sanctus*, *R. divaricatus*, *R. conothyrsoides* and *R. capricollensis*. Raspberry, one of these species, is taxonomically a fruit belonging to the species *Rubus idaeus* Linnaeus (Rosaceae: Rosales) (Hummer, 2010). *R. idaeus*, native to the Americas and Europe, can grow in hilly-mountainous, high altitudes (above 1000 m) and moist-rich soils. Raspberry is one of the horticultural crops that can easily grow anywhere in the world with temperate climatic conditions, even though they originated in America and Europe (Giovanelli et al., 2014). Raspberry, which have a thorny plant structure, can grow about one and a half meters in length and generally bloom white flowers from late June to early July.

A useful characteristic of raspberry is that its fruit remain on the market long enough. Indeed, raspberry can remain intact from approximately mid-July to the end of October, and this advantageous characteristic makes them a very popular product for both producers and consumers (Glisic and Milosevic, 2017). Mostly consumed fresh, raspberries are now widely used in the pharmaceutical, agricultural and food industries as well as the cosmetics industry (Brodowska, 2017; Gomes et al., 2017). The characteristic red berries of raspberries, which can range from small to certain sizes, have a pleasant taste, smell and aroma. The fruiting time of raspberries is usually between June and August. The raspberry leaves, which can be silvery or white in color, are grouped together in groups of three or five on the plant. Most consumers who are interested in this fruit prefer the leaves as much as the fruit itself, and raspberry leaves can be used fresh or dried in the production of herbal teas (Cefali et al., 2019).

As in many European countries, raspberry cultivation is also practiced in Türkiye (Erturk and Gecer, 2012). While fruit production in the country is mainly carried out on the Aegean coast, Bursa province of the Marmara Region ranks first in production. According to raspberry production data for 2022, 6652 tons of raspberries were produced in a total area of 798.1 hectare (ha) in Türkiye (TÜİK, 2022). Raspberries contain significant levels of antioxidants, anthocyanins, vitamin C, minerals, proteins, fatty acids, and carbohydrates, which contribute to the protection and improvement of human and animal health (Kula and Krauze-Baranowska, 2015; Teng et al., 2017; Nowak et al., 2018). Due to their high dietary fiber content, raspberries are widely recommended by dieticians and health professionals for their benefits in a healthy and balanced diet (Li et al., 2019). Raspberries, known for their benefits such as facilitating digestion, strengthening immunity, energizing the body, and regulating blood sugar, are popular for their beneficial properties (Zha and Koffas, 2017).

This study was conducted to determine the agro-morphological characteristics of various raspberry fruit genotypes. The main goal of the study was to document these genotypes and analyze their bioactive properties, which are important for understanding their potential health benefits and agricultural value. In addition, statistical distributions and descriptions of raspberry genotypes based on their agro-morphological characteristics were analyzed in this study.

MATERIAL AND METHOD

Fruit Material

In this study, samples of raspberry genotypes growing naturally in Çivril locality in the central district of Bolu province of Türkiye were taken. In the study, the initial step was fieldwork to identify and collect raspberry fruit samples from the region's various genotypes. Once the samples were gathered, they were carefully placed in suitable containers to ensure their preservation during transport. These containers were labeled with necessary information about the genotypes and locations, and the samples were taken to a laboratory for further analysis. At the laboratory, the agro-morphological characteristics of the raspberry samples, including size, shape, color, and texture, were examined to assess the diversity and quality of the genotypes. Following the initial observations, the fruit samples were frozen at -20°C to preserve their integrity for subsequent analyses. The next phase of the research was focused on analyzing some of the bioactive properties of the raspberry samples. Bioactive compounds are substances found in plants that have an effect on living organisms, including potential health benefits like antioxidant, anti-inflammatory, and antimicrobial effects. In order to assess these properties, advanced laboratory techniques were employed after the samples had been properly stored. All the morphological and physicochemical analyses were conducted at the Faculty of Agriculture Laboratory, Bolu Abant İzzet Baysal University. These analyses provided valuable information about the chemical composition of the raspberry fruits, including factors like acidity, sugar content, and the presence of bioactive compounds, which could be important for both nutritional and commercial purposes. This comprehensive study not only helps to document the diversity of naturally growing raspberry genotypes in the region but also contributes to a better understanding of their potential uses in food, health, and agriculture.

Determination of Agro-Morphological Characteristics of Fruits

In this study, various physical and chemical characteristics of raspberry genotypes were measured using standardized methods to ensure accuracy and consistency. Here's a breakdown of the methods used for each parameter:

Fruit Weight (g): Twenty fruits from each raspberry genotype were randomly selected. These fruits were weighed individually using a precision balance with a sensitivity of 0.01 g. The arithmetic mean of the weight values was then calculated, giving the average fruit weight for each genotype (Kalyoncu, 1996).

Fruit Width and Length (mm): To measure the size of the fruit, 10 fruit samples were randomly selected from each genotype. Their width and length were measured using a caliper sensitive to 0.01 mm, and the results were recorded for each genotype (Kalyoncu, 1996).

Seed Width and Height (mm): The study also focused on seed size. Ten seeds from each genotype were randomly taken and their width and height were measured using a caliper sensitive to 0.01 mm, following the procedure outlined by Karadeniz et al. (1996).

Fruit Stem Thickness and Stem Pit Width (mm): Ten fruit stalk samples were randomly selected from each genotype to measure the thickness of the fruit stem and the width of the stem pit. These measurements were taken using a caliper with a 0.01 mm precision, and the arithmetic mean of the values was calculated to determine the fruit stem thickness and stem pit width (Kalyoncu, 1996).

Fruit Stem Length and Stem Pit Depth (mm): Similar to the measurements for stem thickness, the length of the fruit stem and the depth of the stem pit were measured from 10 randomly selected fruit stalks for each genotype using a 0.01 mm sensitive caliper. The average of these measurements was then calculated (Kalyoncu, 1996).

Soluble Solids Content (SSC) (%): The soluble solids content, which is an indicator of sugar concentration, was determined using a hand refractometer (Atago PAL-1, Washington, USA). This measurement was expressed as a percentage (Esitken, 1992).

Titratable Acidity (TA) (%): To determine the titratable acidity (TA) of the fruit juices, 20 fruits from each genotype were squeezed through cheesecloth to extract their juice. Approximately 10 mL of the extracted juice was diluted to 50 mL with distilled water. The diluted juice was titrated with 0.1 N NaOH until the pH reached 8.1. Based on the amount of NaOH used, the TA value was calculated in terms of malic acid using a specific formula (Karacali, 2002; Tas et al., 2023).

These methods were designed to provide accurate and reliable data on the physical and chemical characteristics of raspberry genotypes, contributing to a better understanding of their agro-morphological and bioactive properties.

$$TA: \frac{NAOH\ spent\ (ml)\ x\ 0.1\ x\ 0.067\ (malic\ acid)\ x\ 100}{amount\ of\ juice\ used\ (ml)} \quad (1)$$

In this section of the study, several additional physical and chemical characteristics of the raspberry genotypes were measured, and statistical analyses were used to evaluate the results. Here's a detailed explanation of the methods used:

SSC/TA Ratio: The ratio of soluble solids content (SSC) to titratable acidity (TA) was calculated by dividing the SSC value by the TA value. This ratio provides a measure of the sweetness-to-acidity balance in the fruit, which is an important factor in flavor quality (Karacali, 2002).

Juice pH Value: To determine the pH of the fruit juice, a homogeneous mixture was prepared by extracting juice from 20 randomly selected fruits. Once the juice reached room temperature, approximately 10 mL of it was placed into a 50 mL beaker, and a pH meter (Thermo, OrionStar A111, USA) was used to measure the pH. The electrode of the pH meter was immersed in the juice mixture, and the reading was recorded once it stabilized (Esitken, 1992).

Fruit Skin Color: The skin color of the raspberries was measured using a Konica Minolta CR-400 colorimeter. Several color parameters were recorded: L*: The luminance value, where 0 indicates black and 100 indicates white. a*: Positive a* values represent red, while negative a* values represent green. b*: Positive b* values represent yellow, while negative b* values represent blue. Chroma: This value represents the intensity or saturation of the fruit skin color. Hue°: This value represents the hue or actual color of the fruit. A hue angle of 0° corresponds to red, 90° corresponds to yellow, 180° corresponds to green, and 270° corresponds to blue. The Hue° value also indicates the distance from the vertical axis in color space, giving an indication of the intensity of the color. These color values were calculated for each fruit using three reciprocal measurements taken from the equatorial region of the fruit, ensuring that the color assessment was consistent across all samples (Ertekin et al., 2006).

Statistical Analysis

To analyze the agro-morphological data collected in the study, Student's t-test (LSD test) was employed to determine if there were significant differences among the genotypes. The experiment was conducted using a randomized plot design with 3 replications, and each replication contained 15 plants. This design ensured that the results were statistically valid and accounted for variability between genotypes. For data analysis, SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA) was used. When pairwise *F* tests showed significant differences, means were compared using Tukey's posthoc test. This test is commonly used in research to compare group means after a significant *F* test, providing detailed insight into which groups differ from each other (Gentleman et al., 2004). These methods ensured that the data collected on fruit weight, color, acidity, and other characteristics were analyzed rigorously, providing statistically valid conclusions about the differences between raspberry genotypes.

RESULTS AND DISCUSSION

Agro-Morphological Characteristics of Fruits

Türkiye due to its favorable geographical location, has a rich diversity of fruits, including raspberries, which are valued for their beneficial phytochemicals. This study focused on selected raspberry genotypes, where fruit samples were collected and subjected to various measurements and analyses to determine their agro-morphological characteristics. The results revealed statistically significant differences among the genotypes with respect to these characteristics, with a significance level of $p \leq 0.05$. A key finding was the significant difference in fruit weight among the genotypes ($p \leq 0.05$). When comparing the genotypes, Genotype 4 exhibited the highest fruit weight at 2.52 g, while Genotype 2 had the lowest fruit weight at 1.30 g. Moreover, genotypes such as Genotype 4 (2.52 g), Genotype 6 (2.49 g), Genotype 8 (2.25 g), and Genotype 5 (2.20 g) stood out in terms of their relatively higher fruit weight (Table 1). The study's findings are consistent with previous research on raspberry fruit weight: Tosun et al. (2009) found fruit weights ranging from 1.47 to 2.32 g in the raspberry variety 'Heritage'. Yang et al. (2020) reported the highest fruit weight of 4.20 g in the raspberry variety 'Tulameen' grown in Shanxi, North China. Augšpole et al. (2021), conducting research in Latvia, found the highest fruit weight of 2.74 g in the 'Polana' variety. Ahmed et al. (2014) recorded the highest fruit weight of 3.49 g in raspberries from the Neriyan Sharif region in Azad Jammu District, Pakistan. Zejak et al. (2021), in their study in Montenegro, reported the highest fruit weight of 3.47 g in the 'Polka' variety. These findings are in line with the results of this study, indicating that raspberry fruit weight can vary significantly depending on the variety and growing conditions. This study adds to the growing body of research on raspberry genotypes, providing valuable insights into their agro-morphological characteristics and helping to inform future breeding and cultivation practices.

The differences among genotypes in terms of fruit width and fruit length data were found statistically significant (p≤0.05). Accordingly, when the genotypes were analyzed, the highest fruit width (18.88 mm) was determined in Genotype 6 and the lowest fruit width (15.33 mm) was determined in Genotype 2. Moreover, when the genotypes were evaluated in terms of high fruit width, Genotype 6 (18.88 mm), Genotype 5 (18.22 mm), Genotype 4 (18.08 mm) and Genotype 3 (17.99 mm) genotypes stood out, respectively (Table 1). When the genotypes were analyzed in terms of fruit length, the highest fruit length (18.45 mm) was determined in Genotype 6 and the lowest fruit length (12.87 mm) was determined in Genotype 2. In addition, when the genotypes were evaluated in terms of high fruit length, Genotype 6 (18.45 mm), Genotype 4 (16.04 mm), Genotype 8 (15.30 mm), Genotype 7 (15.26 mm) and Genotype 1 (15.19 mm) were the dominant genotypes, respectively (Table 1). Ahmed et al. (2014) reported a maximum fruit length of 9.1 mm and a fruit width of 11.4 mm in raspberry fruits from Topa, Azad Jammu Region, Pakistan. In another study, Augšpole et al. (2021) conducted their research in Latvia and reported the highest fruit length (11 mm) in the 'Shahrazada' raspberry variety and the maximum fruit width (49.83 mm) in the 'Daiga' variety. When the data of the above-mentioned literature studies on fruit width and length were analyzed together with the data of this study, similar results were obtained, except for the result of Augšpole et al. (2021) on fruit width. On the other hand, it is thought that the partial difference in the study may be due to genotype/variety, geographical location, ecological factors, soil characteristics and years.

The differences among genotypes in terms of seed width and seed height data were found statistically significant (p≤0.05). Accordingly, when the genotypes were analyzed, the highest seed width (1.30 mm) was determined in Genotype 4 and the lowest seed width (1.10 mm) was determined in Genotype 6. Moreover, when the genotypes were evaluated in terms of high seed width, Genotype 4 (1.30 mm), Genotype 1 (1.28 mm), Genotype 5 (1.27 mm) and Genotype 2 (1.26 mm) genotypes stood out, respectively (Table 1). When the genotypes were analyzed in terms of seed height, the highest seed height (2.37 mm) was determined in Genotype 1 and the lowest seed height (1.84 mm) was determined in Genotype 6. In addition, when the genotypes were evaluated in terms of high seed height, Genotype 1 (2.37 mm), Genotype 3 (2.14 mm), Genotype 4 (2.10 mm), Genotype 5 (2.02 mm) and Genotype 2 (2.00 mm) were the dominant genotypes, respectively (Table 1). No literature study was found in terms of seed width and height in raspberries, and it is thought that the data obtained in this study on seed width and height may contribute to various researches on this subject.

While the differences among genotypes in terms of fruit stem thickness, fruit stem pit depth and fruit stem pit width data were statistically significant (p≤0.05), the differences among genotypes in terms of fruit stem length were not statistically significant (p≥0.05). Accordingly, when the genotypes were analyzed in terms of fruit stem thickness, the highest fruit stem thickness (0.91 mm) was determined in Genotype 4 and the lowest fruit stem thickness (0.67 mm) was determined in Genotype 5. Moreover, when the genotypes were evaluated in terms of high fruit stem thickness, Genotype 4 (0.91 mm), Genotype 8 (0.80 mm), Genotype 6 (0.76 mm)=Genotype 7 (0.76 mm)=Genotype 9 (0.76 mm) genotypes stood out, respectively. When the genotypes were analyzed in terms of fruit stem pit depth, the highest fruit stem pit depth (13.99 mm) was determined in Genotype 6 and the lowest fruit stem pit depth (10.58 mm) was determined in Genotype 5. In addition, when the genotypes were evaluated in terms of high fruit stem pit depth, Genotype 6 (13.99 mm), Genotype 8 (12.42 mm) and Genotype 4 (12.40 mm) genotypes were more dominant, respectively. When the genotypes were analyzed in terms of fruit stem pit width, the highest fruit stem pit width (10.08 mm) was determined in Genotype 4 and the lowest fruit stem pit width (7.82 mm) was determined in Genotype 9. Furthermore, when the genotypes were evaluated in terms of high fruit stem pit width, Genotype 4 (10.08 mm), Genotype 7 (9.46 mm), Genotype 8 (9.23 mm), Genotype 6 (9.10 mm) and Genotype 3 (8.97 mm) stood out, respectively (Table 2). There is no literature study on fruit stem thickness, fruit stem pit depth and fruit stem pit width in raspberry, and it is thought that the results obtained in this study may contribute to various researches on this subject.

Table 1. Determination of seed height, seed width, fruit weight, fruit length and fruit width values in raspberry genotypes.
Çizelge 1. Ahududu genotiplerinde çekirdek boyu, çekirdek eni, meyve ağırlığı, meyve boyu ve meyve eni değerlerinin belirlenmesi.

Genotypes	Seed height (mm)	Seed width (mm)	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)
Genotype 1	2.37 ± 0.11 a*	1.28 ± 0.05 a	1.95 ± 0.11 c	15.19 ± 0.62 bc	17.72 ± 0.44 bc
Genotype 2	2.00 ± 0.07 bcd	1.26 ± 0.06 ab	1.30 ± 0.06 d	12.87 ± 0.27 e	15.33 ± 0.31 d
Genotype 3	2.14 ± 0.05 b	1.24 ± 0.04 abc	1.92 ± 0.05 c	13.96 ± 0.29 de	17.99 ± 0.26 abc
Genotype 4	2.10 ± 0.07 b	1.30 ± 0.06 a	2.52 ± 0.10 a	16.04 ± 0.31 b	18.08 ± 0.35 abc
Genotype 5	2.02 ± 0.04 bc	1.27 ± 0.05 ab	2.20 ± 0.05 b	14.98 ± 0.43 bcd	18.22 ± 0.32 ab
Genotype 6	1.84 ± 0.05 d	1.10 ± 0.04 c	2.49 ± 0.11 a	18.45 ± 0.49 a	18.88 ± 0.39 a
Genotype 7	1.96 ± 0.06 bcd	1.17 ± 0.04 abc	1.92 ± 0.04 c	15.26 ± 0.27 bc	17.22 ± 0.26 c
Genotype 8	1.97 ± 0.07 bcd	1.22 ± 0.05 abc	2.25 ± 0.09 b	15.30 ± 0.65 bc	17.90 ± 0.28 bc
Genotype 9	1.90 ± 0.04 cd	1.14 ± 0.05 bc	1.88 ± 0.07 c	14.68 ± 0.30 cd	17.46 ± 0.33 bc

Table 2. Determination of fruit stem thickness, fruit stem length, fruit stem pit depth and fruit stem pit width values in raspberry genotypes.
Çizelge 2. Ahududu genotiplerinde meyve sap kalınlığı, meyve sap uzunluğu, meyve sap çukur derinliği ve meyve sap çukur genişliği değerlerinin belirlenmesi.

Genotypes	Fruit stem thickness (mm)	Fruit stem length (mm)	Fruit stem pit depth (mm)	Fruit stem pit width (mm)
Genotype 1	0.68 ± 0.02 b*	22.18 ± 2.40 a	11.31 ± 0.34 bc	8.37 ± 0.27 de
Genotype 2	0.68 ± 0.08 b	24.18 ± 1.00 a	10.82 ± 0.34 c	7.93 ± 0.17 e
Genotype 3	0.69 ± 0.07 b	21.53 ± 2.00 a	10.85 ± 0.42 c	8.97 ± 0.24 bcd
Genotype 4	0.91 ± 0.04 a	23.41 ± 1.84 a	12.40 ± 0.48 b	10.08 ± 0.54 a
Genotype 5	0.67 ± 0.03 b	21.93 ± 1.50 a	10.58 ± 0.22 c	8.61 ± 0.23 cde
Genotype 6	0.76 ± 0.04 ab	20.52 ± 0.67 a	13.99 ± 0.62 a	9.10 ± 0.34 bcd
Genotype 7	0.76 ± 0.05 ab	20.74 ± 0.52 a	11.70 ± 0.25 bc	9.46 ± 0.28 ab
Genotype 8	0.80 ± 0.03 ab	21.00 ± 0.50 a	12.42 ± 0.65 b	9.23 ± 0.24 bc
Genotype 9	0.76 ± 0.06 ab	21.66 ± 0.48 a	10.91 ± 0.45 c	7.82 ± 0.21 e

*: The difference between the means indicated with the same letter in the same column is insignificant ($P<0.05$).

When the data were evaluated in terms of the SSC ratio, the differences between the genotypes were found to be statistically significant ($p\leq0.05$). Accordingly, when the genotypes were analyzed, the highest SSC content (13.80%) and the lowest SSC content (8.10%) were found in Genotype 3 and Genotype 5, respectively. In addition, when the genotypes were evaluated in terms of high SSC content, Genotype 3 (13.80%), Genotype 2 (13.73%), Genotype 7 (10.33%) and Genotype 8 (9.08%) were in the forefront, respectively (Table 3). Tosun et al. (2009) found that the SSC content of raspberry variety named 'Heritage' ranged between 10.87-13.60%. Zejak et al. (2021), in their study carried out in Montenegro, reported the highest SSC content as 13.63% in 'Polka' raspberry variety. Dujmović Purgar et al. (2012), in their study on raspberries in Croatia, observed that the highest SSC content was 11.50%. Giuffrè et al. (2019) found that the highest SSC content in raspberry was 9.44%. The results of the above-mentioned literature studies on the SSC content and the SSC results of this study supported each other.

When the TA values of the fruit juices of raspberry genotypes were analyzed, statistically significant differences were found ($p\leq0.05$). Accordingly, the highest TA value (3.60%) was found in Genotype 9 and the lowest TA value (1.98%) was found in Genotype 2. In addition, when the genotypes were evaluated in terms of high TA value, Genotype 9 (3.60%), Genotype 3 (3.40%), Genotype 6 (3.13%), Genotype 7 (3.10%)

and Genotype 8 (3.06%) genotypes stood out, respectively (Table 3). Ahmed et al. (2014) determined the highest TA value as 2.17% in raspberry fruits from Neriyan Sharif location of Azad Jammu District of Pakistan. Dujmović Purgar et al. (2012) observed the highest TA value of 1.91% in raspberries from Croatia. Giuffrè et al. (2019) found the highest TA value in raspberries as 2.08%. When the results of the above-mentioned literature studies in terms of TA values in raspberry were compared with the results of this study, it was concluded that the studies supported each other. Regarding the subject, Davarynejad et al. (2013) reported that the titratable acidity values determined in fruits could be directly related to the respiration rate and ethylene synthesis processes in the fruit. In addition, it is thought that the differences observed between studies may be due to factors such as genotype, geographical location, ecological conditions, soil properties and years. When raspberry genotypes were evaluated in terms of SSC/TA ratio, statistically significant differences were found ($p \leq 0.05$). Accordingly, the highest SSC/TA ratio (6.93) was found in Genotype 2 and the lowest SSC/TA ratio (2.38) was found in Genotype 9. Moreover, when the genotypes were analyzed in terms of high SSC/TA ratio, it was observed that Genotype 2 (6.93), Genotype 1 (4.32) and Genotype 3 (4.05) genotypes were more prominent, respectively (Table 3). When the data were analyzed in terms of juice pH, statistically significant differences were found between the pH values of the juices of raspberry genotypes ($p \leq 0.05$). Accordingly, the highest pH value (3.29) among the genotypes was found in Genotype 2. It was also found that the pH values observed in all genotypes in the study were very close to each other (between 3.06 and 3.29) (Table 3). Augšpole et al. (2021), in their study conducted in Latvia, examined the highest pH value of 3.23 in 'Daiga' raspberry variety. Ahmed et al. (2014) determined the highest pH value as 3.05 in raspberry fruits from Neriyan Sharif location of Azad Jammu District of Pakistan. Dujmović Purgar et al. (2012) observed the highest pH value as 3.18 in their study on raspberries in Croatia. The results of the sample literature studies given above in terms of pH value and the pH value results in this study supported each other.

Table 3. Determination of pH, soluble solids content (SSC), titratable acidity (TA) value and SSC/TA values in raspberry genotypes.

Çizelge 3. Ahududu genotiplerinde pH, çözünebilir katı madde miktarı (SÇKM), titre edilebilir asitlik (TEA) değeri ve SÇKM/TEA değerlerinin belirlenmesi.

Genotypes	pH	SSC (%)	TA (%)	SSC/TA
Genotype 1	3.18 ± 0.01 b	8.73 ± 0.24 cd	2.02 ± 0.95 e	4.32 ± 0.02 b
Genotype 2	3.29 ± 0.05 a	13.73 ± 0.24 a	1.98 ± 0.95 e	6.93 ± 0.03 a
Genotype 3	3.17 ± 0.02 b	13.80 ± 0.23 a	3.40 ± 0.37 e	4.05 ± 0.01 bc
Genotype 4	3.06 ± 0.03 c	8.33 ± 0.38 cd	2.32 ± 0.22 a	3.59 ± 0.02 cd
Genotype 5	3.10 ± 0.04 bc	8.10 ± 0.57 d	2.60 ± 0.60 d	3.11 ± 0.03 e
Genotype 6	3.06 ± 0.05 c	8.23 ± 0.15 cd	3.13 ± 0.41 c	2.62 ± 0.01 fg
Genotype 7	3.09 ± 0.02 bc	10.33 ± 0.35 b	3.10 ± 0.35 b	3.33 ± 0.01 de
Genotype 8	3.18 ± 0.03 b	9.08 ± 0.26 c	3.06 ± 0.43 b	2.96 ± 0.02 ef
Genotype 9	3.09 ± 0.02 bc	8.60 ± 0.23 cd	3.60 ± 0.53 b	2.38 ± 0.01 g

*: The difference between the means indicated with the same letter in the same column is insignificant ($P<0.05$).

In this study, the skin color of raspberry fruits was analyzed using the L*, a*, b* color model, and significant differences between the genotypes were observed in terms of these parameters ($p \leq 0.05$). L* Value (Lightness/Darkness): The L* value indicates the lightness of the fruit skin, with higher values corresponding to lighter colors and lower values to darker colors. Upon analyzing the data, statistically significant differences were found in L* values between the genotypes. The genotype with the lightest fruit color was Genotype 8, with an L* value of 32.22. This was followed by Genotype 6 (31.93), Genotype 2 (31.73), Genotype 9 (31.68), Genotype 5 (31.62), and Genotype 4 (31.19). The darkest fruit color was observed in Genotype 1, which had an L* value of 28.82 (Table 4). a* Value (Red-Green Chromaticity): The a* value represents the red-green chromaticity axis, with positive values indicating a red hue and negative values indicating green. Significant differences were found among the raspberry genotypes for a* values. The highest a* value, indicating the most intense red color, was observed in Genotype 1 (23.75), followed by Genotype 9 (23.31) and Genotype 4 (23.03). On the other hand, the lowest a* value, indicating less redness, was observed in Genotype 6 (19.73) (Table 4). b* Value (Yellow-Blue Chromaticity): The b* value measures the yellow-blue axis, where positive b* values indicate yellow and negative b* values indicate blue. In this study, significant differences were observed in b* values across genotypes. The genotype with the highest b* value, indicating the most yellow hue, was Genotype 1 (12.86), followed by Genotype 9 (11.41) and Genotype 4 (10.71). The lowest b* value was found in Genotype 7 (9.18), indicating less yellow and a shift toward blue (Table 4). Overall, these results show that raspberry genotypes exhibit a wide range of skin color characteristics. Genotype 1 stands out with the darkest and most intensely red fruit color, along with the highest yellow hue, while Genotype 8 has the lightest skin color. These color differences are important in consumer preference and can also be indicators of phytochemical content, especially anthocyanins, which contribute to the red pigmentation in raspberries. The statistical significance of these differences ($p \leq 0.05$) reinforces the variation in fruit skin color among the raspberry genotypes studied.

In this study, additional parameters of fruit skin color, including chroma and hue° values, were measured alongside the L*, a*, and b* values. Statistically significant differences were found between the raspberry genotypes for these color characteristics ($p \leq 0.05$), adding further insight into the variation in fruit appearance among the genotypes. b* Value (Yellow-Blue Chromaticity, Continued): Along with the genotypes mentioned earlier, other genotypes with relatively high b* values, which indicate a stronger yellow hue, were Genotype 3 (10.43), Genotype 6 (9.94), Genotype 5 (9.91), and Genotype 2 (9.80) (Table 4). Chroma (Color Intensity/Saturation): The chroma value refers to the intensity or saturation of the fruit's color, with higher values indicating more vivid color. The differences in chroma values among the raspberry genotypes were statistically significant ($p \leq 0.05$). Genotype 1 had the highest chroma value (27.10), showing the most intense color, while Genotype 6 had the lowest chroma value (22.11), indicating a less saturated color. Genotype 1 was followed by Genotype 9, which had a chroma value of 25.96 (Table 4). Hue° Value (Color Tone/Intensity): The hue° value represents the specific shade or tone of the color and is a measure of the angular distance in color space, with different angles corresponding to different hues. Statistically significant differences ($p \leq 0.05$) were found in hue° values among the genotypes. Genotype 1 exhibited the highest hue° value (28.22), indicating the most intense color, while the lowest hue° values (23.76) were observed in both Genotype 7 and Genotype 8. Genotype 1 was followed by Genotype 6 (26.73), Genotype 2 (26.17), and Genotype 9 (26.04) in terms of hue° intensity (Table 4). These findings are consistent with previous research. For instance, Augšpole et al. (2021), in their study conducted in Latvia, determined the highest L*, a*, and b* values as 29.13, 17.32, and 7.77, respectively, in the 'Daiga' raspberry variety. When compared to the results of this study, the L*, a*, and b* values for various genotypes align well with these findings, indicating that the studies support each other. Both studies highlight the diversity in skin color characteristics among different raspberry varieties, which can influence consumer appeal and market value. These color parameters—L*, a*, b*, chroma, and hue°—are important in evaluating the visual quality of raspberries, which is a key factor in consumer preferences and marketability.

The principal coordinate plane distributions of the correlation between agromorphological and biochemical traits of fruits of raspberry genotypes identified by PC analysis are given in Figure 1. It is seen that the total variation is significantly explained by the first two principal component axes with a value of 47.3%. The first principal component axis accounts for 27.8% of the total variation and the second principal component axis accounts for 19.5% of the total variation. These axes were found to be important in the evaluation of the analysis. Among the parameters defined by PC analysis, color values (L*, a*, b*, Chroma and Hue°) are in parallel with each other and have a positive relationship. Similarly, fruit weight, fruit width and fruit length are parallel to each other. While a negative correlation was observed between fruit stem length and fruit stem thickness, a positive correlation was observed between seed width and seed height. Similarly, a positive correlation was observed between the ratio of SSC/TA and pH, while a negative correlation was observed between SSC and TA (Figure 1).

Table 4. Determination of fruit skin color characteristics in raspberry genotypes.
Çizelge 4. Ahududu genotiplerinde meyve kabuk rengi özelliklerinin belirlenmesi.

Genotypes	L*	a*	b*	Chroma	Hue°
Genotype 1	28.82 ± 1.17 c*	23.75 ± 0.82 a	12.86 ± 0.99 a	27.10 ± 1.04 a	28.22 ± 1.63 a
Genotype 2	31.73 ± 0.40 ab	19.88 ± 0.58 e	9.80 ± 0.42 bc	22.18 ± 0.68 d	26.17 ± 0.56 abc
Genotype 3	30.53 ± 0.62 abc	21.37 ± 0.95 b-e	10.43 ± 0.72 bc	23.80 ± 1.14 bcd	25.76 ± 0.89 bcd
Genotype 4	31.19 ± 0.92 ab	23.03 ± 0.63 abc	10.71 ± 0.50 bc	25.39 ± 0.75 abc	24.88 ± 0.60 bcd
Genotype 5	31.62 ± 0.37 ab	22.12 ± 0.62 a-d	9.91 ± 0.40 bc	24.24 ± 0.72 bcd	24.07 ± 0.31 cd
Genotype 6	31.93 ± 0.49 ab	19.73 ± 0.89 e	9.94 ± 0.52 bc	22.11 ± 1.01 d	26.73 ± 0.57 ab
Genotype 7	30.06 ± 0.30 bc	20.65 ± 0.86 de	9.18 ± 0.62 c	22.32 ± 1.15 d	23.76 ± 0.83 d
Genotype 8	32.22 ± 1.02 a	20.90 ± 0.92 cde	9.22 ± 0.51 c	22.85 ± 1.04 cd	23.76 ± 0.36 d
Genotype 9	31.68 ± 0.38 ab	23.31 ± 0.66 ab	11.41 ± 0.43 ab	25.96 ± 0.77 ab	26.04 ± 0.39 abc

*: The difference between the means indicated with the same letter in the same column is insignificant (P<0.05).

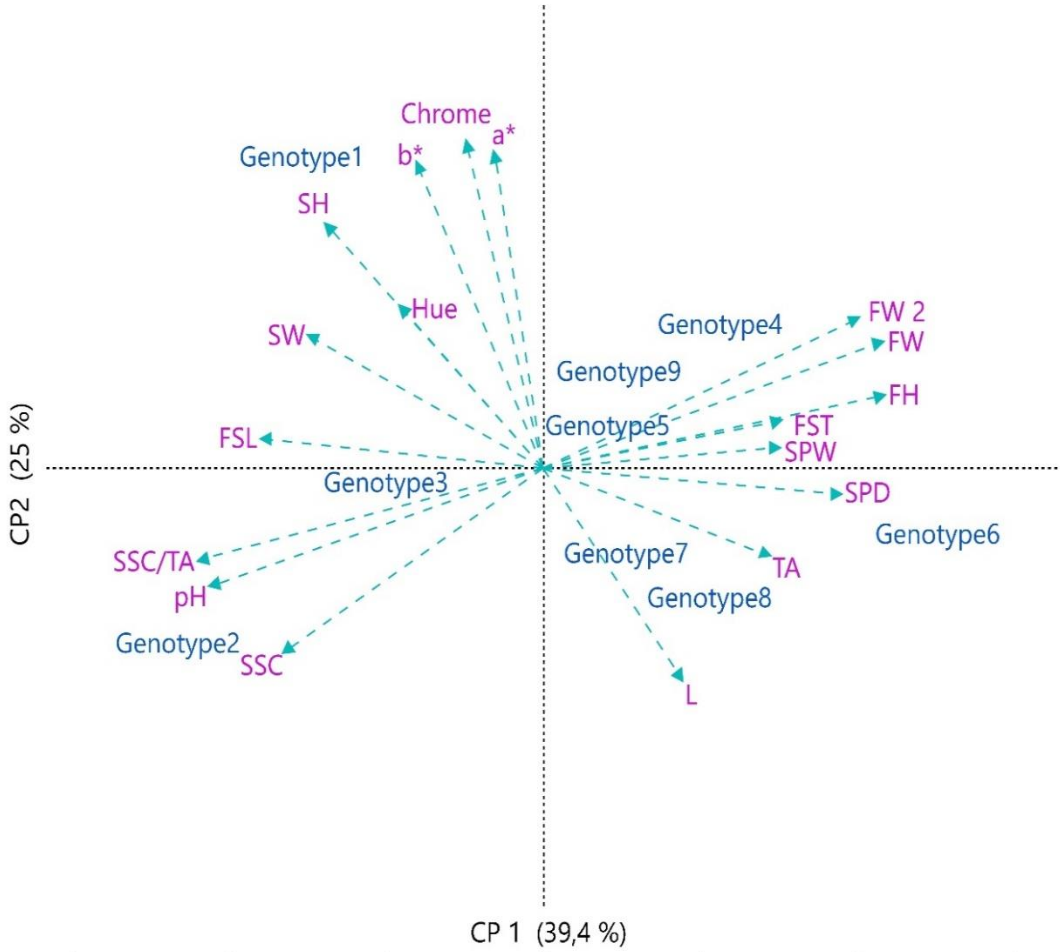

Figure 1. Distribution of agromorphological and chemical components of raspberry genotypes according to principal component analysis. FW: Fruit Weight, FW 2: Fruit Width, FH: Fruit Height, SPW: Stem Pit Width, SPD: Stem Pit Depth, FSL: Fruit Stem Length, FST: Fruit Stem Thickness, SW: Seed Width, SH: Seed Height, SSC: Soluble solids content, TA: Titratable acidity.

Şekil 1. Ahududu genotiplerinin agromorfolojik ve kimyasal bileşenlerinin temel bileşen analizine göre dağılımı. FW: Meyve Ağırlığı, FW 2: Meyve Eni, FH: Meyve Boyu, SPW: Sap Çukur Genişliği, SPD: Sap Çukur Derinliği, FSL: Meyve Sap Uzunluğu, FST: Meyve Sap Kalınlığı, SW: Çekirdek Eni, SH: Çekirdek Boyu, SSC: Çözünebilir Katı Madde Miktarı, TA: Titre EdilebilirAsitlik.

Cluster analysis was performed among agromorphological and biochemical compounds in raspberry genotypes. In the hierarchical clustering analysis, the genotypes were divided into four different clusters. In genotype 1 measurements, a*, b*, chroma and Hue° values, seed width and seed height were found significant, while L* and titratable acidity values were found insignificant. Genotype 2 fruits were found to be significant in terms of pH, SSC/TA and SSC values and they formed a separate cluster. Fruit weight, fruit width, fruit length and fruit stem pit were found to be significant in the analysis of genotype 6 fruits, whereas fruit stem length, seed width, seed height, pH, SSC/TA, SSC, a* and chroma values were found to be insignificant and formed a separate cluster (Figure 2).

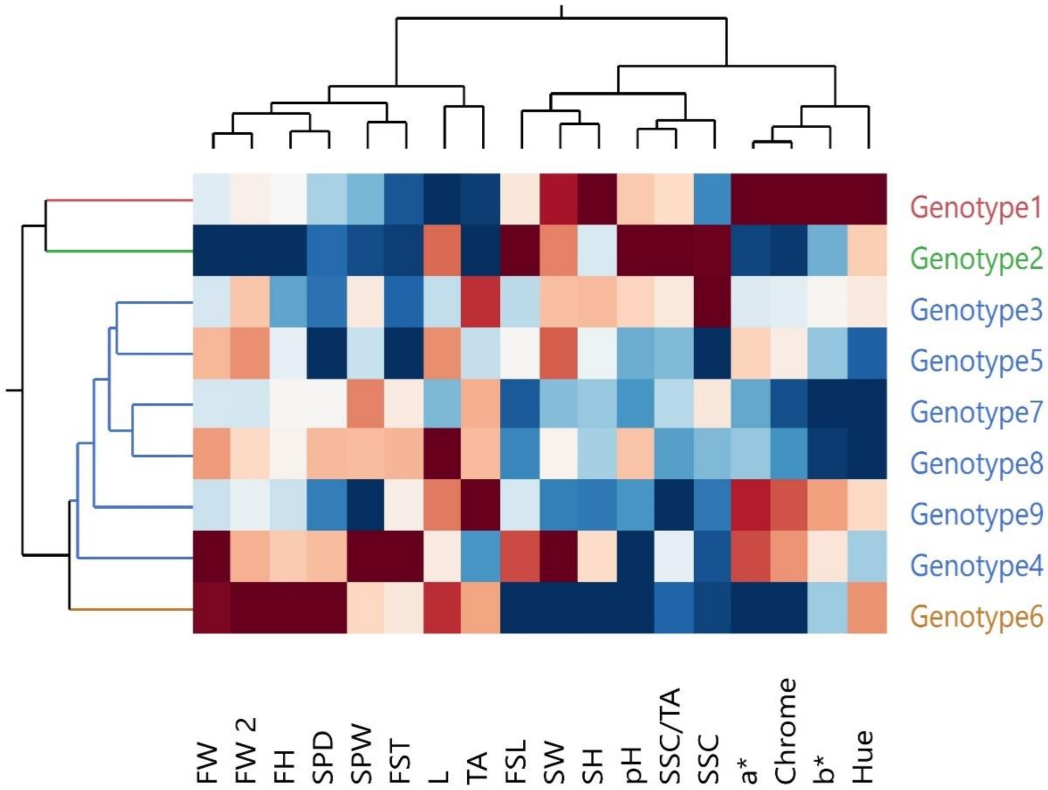

Figure 2. Heatmap analysis of agromorphological and biochemical compounds of raspberry genotypes. The color scale color from blue to red shows the minimum to maximum values for each trait.

Şekil 2. Ahududu genotiplerinin agromorfolojik ve biyokimyasal bileşiklerinin ısı harita analizi. Mavi ile kırmızı arasındaki renk skalası her özellik için minimumdan maksimuma değerleri gösterir.

CONCLUSION

In this study, agro-morphological characteristics of fruits of 9 raspberry genotypes grown in Bolu province were investigated. It was determined that Genotype 4 (2.52 g) was promising in terms of fruit weight in terms of agro-morphological content. In addition, in genotypes, the highest fruit width and length were found in Genotype 6 (fruit width: 18.18 mm, fruit length: 18.45 mm) and the highest seed width and height were found in Genotype 4 (1.30 mm) and Genotype 1 (2.37 mm) genotypes, respectively. Genotype 4 (0.91 mm), Genotype 6 (13.99 mm) and Genotype 4 (10.08 mm) genotypes were more prominent in the parameters of fruit stem thickness, fruit stem pit depth and fruit stem pit width, respectively, and no statistically significant difference was observed between the genotypes in the fruit stem length parameter.

The content of the SSC in fruits is one of the main criteria that is important in determining the ripeness period of a fruit and thus directly affects consumption. In this study, Genotype 3 genotype was significantly superior to the other genotypes in terms of the highest SSC content (13.80%). Genotype 9 was more dominant in terms of the highest TA value (3.60%). On the other hand, in the study, Genotype 2 genotype was more prominent in terms of high pH value, while the pH values observed in all genotypes ranged between 3.06 and 3.29. In the study, Genotype 1 (a*: 23.75, b*: 12.86, chroma: 27.10, hue°: 28.22) was significantly more dominant than the other genotypes in terms of a*, b*, chroma and hue° values, while Genotype 8 had better L* color value (L* value 32.22). Accordingly, as a result of the study, it was concluded that various genotypes that stand out in terms of agro-morphological characteristics can be evaluated as breeding material in functional raspberry production.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding this article.

DECLARATION OF ETHICS COMMITTEE

This study did not require any ethics committee decision/report.

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