



RELATIONSHIPS BETWEEN FRUIT GROWTH DYNAMICS AND LEAF PHYSIOLOGICAL AND FRUIT COLOR CHARACTERISTICS IN JUJUBE

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Abstract: This study investigated fruit growth dynamics in two different sizes of jujube and their relationships with leaf traits physiological and color characteristics. Fruit and leaf measurements were taken in five different periods between July and September. The large-fruited genotype showed a significant advantage in fruit size compared to the small-fruited type. Chlorophyll content and leaf area were consistently higher in the large-fruited genotype and increased throughout development. Fruit peel color a* values in large-fruited jujube gradually increased, showing a progressive transition from green to red, while a more abrupt reddening was observed in small-fruited jujubes. Correlation analysis identified strong positive relationships between fruit weight, fruit diameter, fruit length, chlorophyll content, leaf area, and fruit peel a* values, defining them as key indicators for fruit size and ripening.

Keywords: Jujube, Growth curve, Fruit weight, SPAD

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1. Introduction

Jujube (*Ziziphus jujuba* Mill.), belonging to the Rhamnaceae family, has a cultural history dating back more than 4000 years and is considered a superfruit in traditional medicine (Krishna et al., 2016). *Z. jujuba* is notable for its ability to adapt to harsh climatic conditions and different soil types. It thrives in hot and dry climates and is known to withstand winter temperatures as low as -29 °C (Khadivi, 2023). Jujube trees can yield sufficient fruit even under environmental stress in drought conditions (Sulusoglu et al., 2014). Jujube trees, which generally have a thorny structure (Khadivi, 2023), bloom in clusters on leaf axils between May and July (Sapkota et al., 2020). The fruits are mostly consumed fresh, but they can also be dried and used in the production of various products such as compotes, and confectionery (Bak, 2023). Jams and jellies are considered promising processed foods (Rashwan et al., 2020). Jujube fruits are a good source of phenolic compounds and antioxidants and can be used as food and nutraceutical supplements (Kamiloglu et al., 2009). The use of jujube fruit, leaves, and seeds in folk medicine has been known for many years (Karadeniz, 2004).

The ripening of jujube fruit progresses through three main stages, depending on changes in color, skin hardness, and composition (starch, sugar, acid, water). In the first stage, white ripeness, the fruit reaches almost its

full size. At this stage, the skin turns from green to greenish-white, while the fruit juice is low and the sugar and starch content is high. In the second stage, crisp ripeness, part of the fruit skin turns red, thickens, hardens, and separates easily from the flesh. In this second stage, the fruit juice is crisp, juicy, sweet, and contains more sugar and acid. In the final stage, full ripeness, the sugar content of the fruit juice increases rapidly while the water content begins to decrease. The skin turns dark red, and the fruit shrinks. These three stages of ripening are the key factors that determine the specific uses and characteristics of jujube fruits (Shahrajabian et al., 2020).

In jujube, fruit size and weight directly affect yield, while peel color and fruit shape are critical in assessing fruit quality (Şumalan et al., 2025). It has been noted that fruit weight variation between genotypes, even within the same geographical regions, stems from genetic and ecological differences (Shahzad et al., 2018), and that genotypes with high fruit weight are important for fresh consumption, while fruit length and width are important traits for breeding programs (Liu et al., 2009). Cultivated fruit varieties generally have larger fruit sizes than their wild counterparts. Cultivated jujube trees can produce fruit that is more fleshy and larger than 10 g, compared to the fruit of wild types, which are mostly less than 5 g (Şumalan et al., 2025). In Türkiye, jujube is a valuable fruit that is preferred for fresh consumption due to its



high fruit quality and size, and its increasing popularity has accelerated the establishment of new orchards in recent years. Jujube production in our country, which was 142 tons on 458 decares in 2013, has reached 3.010 tons on 3.212 decares today. Denizli province ranks among the top producers of jujube in Türkiye, with the district of Çivril within the province's borders being the largest jujube production center (TÜİK, 2024). In this study conducted in Çivril, one of the important production centers where this increase has been observed, the fruit growth dynamics and related characteristics of jujube genotypes of different sizes were examined.

Studies in literature that address fruit development based on phenological stages are more limited compared to other quality-focused studies. However, presenting fruit growth dynamics in stages is important in terms of selecting the right timing, evaluating yield and quality criteria in a comparable manner, and explaining species/variety differences. Defining fruit growth dynamics with sigmoid models is widely accepted in different fruit species (Salinas et al., 2019; Pehlivan et al., 2021). However, although limited, studies reporting fruit development between July and October (Ma et al., 2021) and studies reporting eight main phenological stages in the growth process (Sapkota et al., 2020) contribute to jujube studies but also indicate the continuing need for similar research on different ecologies and materials. The possibility that the fruit growth curve may vary depending on the variety and environmental conditions is also supported by the reporting of a double sigmoid growth curve based on fruit diameter and fresh weight in *Ziziphus jujuba* Mill. cv. Changhong (Lu et al., 2012). Therefore, modeling the growth dynamics of different genotypes in different ecosystems using appropriate models is important both for interpreting developmental stages and for harvest/selection decisions. In this study, growth curves related to fruit weight, diameter, and length were created for two different jujube varieties with large and small fruit sizes grown under similar cultivation conditions in the Çivril district of Denizli province. creating growth curves for fruit weight, diameter, and length, examining changes in leaf area, SPAD values, and fruit and leaf color parameters throughout the development periods, and determining

the relationships between fruit size and leaf characteristics and color parameters through correlation analysis. The findings are expected to provide a scientific basis for selection, cultivation practices, and breeding programs to increase jujube fruit size and quality.

2. Materials and Methods

2.1. Plant Material and Experimental Area

This study was conducted on two types of jujubes that differ in fruit size. One of these jujubes is a large-fruited jujube, while the other represents a wild, small-fruited jujube population. Both jujube genotypes are grown in a commercial farmer's orchard located in the Işıklı neighborhood of Çivril district (Denizli province, Türkiye) under similar conditions. The trees are 10-15 years old, and standard cultural practices, including irrigation, fertilization, and pruning, were applied equally to all trees. The monthly average temperature, relative humidity, and total precipitation data for the long-term period 2007–2023 and for the year 2024 in Çivril district (Figure 1) show distinct seasonal variations. According to long-term (2007–2023) averages, winter months in Çivril are cold (January 3.4 °C; February 5.3 °C), while summer months are hot (July-August 25.4 °C). Precipitation is generally concentrated in the winter and spring months (January 62.7 mm; May 56.1 mm), while the summer months are dry (July 4.4 mm). Relative humidity is high in winter (January 73.8%) and low in summer (July 41.2%). When examining the climate conditions in 2024, they differed slightly from the long-term averages. In terms of temperatures, April 2024 was observed to be significantly above the long-term average (12.2 °C) at 16.1 °C, while June and July 2024 (26.6 °C and 26.5 °C) were 1–5 °C higher than average. In terms of relative humidity, January (81.4%) and December (85.3%) 2024 were above the long-term average, while June 2024 (40.9%) was below. Precipitation was below the long-term average in January (46.9 mm) and February (22.6 mm) 2024, while there was almost no precipitation in September (0.3 mm) and October (0.1 mm) 2024. In contrast, July 2024 saw a relatively high rainfall of 28.7 mm compared to the long-term average. Overall, 2024 was a warmer year, especially in late spring and summer, with increased irregularities in the rainfall regime (TSMS, 2025).

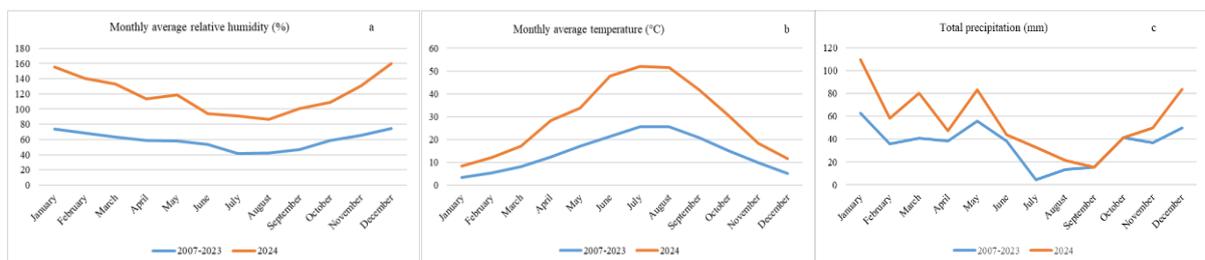


Figure 1. Monthly average relative humidity (%) (a), temperature (°C) (b), and total precipitation (mm) (c) for Çivril district: long-term (2007-2023) averages vs. 2024 values.

2.2. Growth Stages and Measurements

In this study, the fruit and leaf development of both jujube varieties were examined in five different stages. The growth stages were monitored at specific intervals from the third week of July to the third week of September; defined as t1 (July 18, 2025), t2 (August 2, 2025), t3 (August 17, 2025), t4 (September 4, 2025), and t5 (September 20, 2025). Four replicates were used for each period in both jujube trees, and measurements were performed on a total of 40 samples, with 10 fruits and 10 leaves in each replicate. During the development periods, fruit diameter (FD), fruit length (FL), fruit weight (FW), and fruit color were determined. Fruit diameter and fruit length were measured using a digital caliper with 0.01 mm accuracy, considering the widest transverse and longitudinal axes of the fruit. Fruit weight was measured using a digital scale with a precision of 0.01 g. Leaf area, chlorophyll value (SPAD), and leaf color were determined for the leaves. Leaf area was measured using a leaf area meter (YMJ-B), and chlorophyll content was measured using a portable SPAD (Falker brand CFL260). Leaf and fruit colors were determined using a colorimeter (PCE-CSM 1) in terms of L* (lightness), a* (green-red), b* (blue-yellow), C* (chroma/saturation), and h° (hue/color tone) parameters.

2.3. Statistical Analyses

In the study, data on fruit and leaf characteristics were analyzed using a two-way analysis of variance (ANOVA) across the development periods (I-V). For significant differences, the means were compared using Tukey's HSD multiple-comparison test at a 5% significance level. Pearson correlation analysis was performed to determine the relationships among SPAD, LA (Leaf Area), FW (Fruit Weight), FD (Fruit Diameter), FL (Fruit Length), and color parameters (L*, a*, b*, c*, hue°). All statistical analyses and multiple comparisons were performed using JMP Pro 17 (SAS Institute Inc.) software.

3. Results and Discussion

3.1. Changes in Fruit and Leaf Characteristics throughout Developmental Stages

The leaf chlorophyll content, leaf area, and leaf color parameters (L*, a*, b*, Chroma*, hue°) of large-fruited and small-fruited jujubes exhibited different patterns of change throughout their development periods (Table 1). SPAD values showed a steady increase in large-fruited jujube from period t1 to period t5, rising from 41.38 to 48.90, while in small-fruited jujube, they followed a more fluctuating course, remaining at a lower level than large-fruited jujube in period t5. Leaf area increased in both jujubes as the periods progressed. However, large-fruited jujube had higher LA values in all periods. In small-fruited jujubes, LA became particularly pronounced during the t4 and t5 stages. When color parameters were examined, it was observed that the large-fruited genotype generally had a brighter color, despite a decrease in the L* value in leaf color in some periods, while the a* value increased as the periods progressed,

reaching a maximum in period t5. In contrast, the a* values in the small-fruited jujube remained constant (t1 and t2) and low (t4) between periods, suggesting that the color transformation was more limited. In terms of b*, chroma*, and hue° parameters, the large-fruited genotype showed a decreasing trend in yellowness and color saturation throughout the periods, while a shift from green to red was observed in hue°. In contrast, the small-fruited genotype showed more limited changes, mostly remaining at statistically similar levels between periods. The study reveals that large-fruited jujubes exhibit more pronounced changes and differentiation in SPAD, LA, and color characteristics (L*, a*, b*, c*, h°) throughout development, whereas these changes occur within a narrower range in small-fruited varieties. It has been reported that chlorophyll fluorescence parameters in the Changhong variety are related to quality components during the ripening period (Lu et al., 2012). In this context, SPAD and leaf area along with growth indicators are relevant to the growth-physiology relationship in this study.

When examining the changes in fruit peel color characteristics, fruit weight, fruit diameter, and fruit length throughout the development periods, significant differences were observed between jujube fruits of different sizes (Figure 2). In large-fruited jujube, the L* value was 54.56 in period t1 and increased to 68.76 in period t5, indicating that the brightness of the fruit peel increased in the final period compared to the initial period. In small-fruited jujube, the L* value decreased from 58.81 in period t1 to 39.08 in period t5, indicating that the skin darkened. The a* value increased from -3.73 in the t1 period to 3.54 in the t5 period in large-fruited jujube, indicating a color change from green to red, meaning that the fruit began to ripen.

In small-fruited jujube, the a* value increased from -5.75 in period t1 to 29.94 in period t5, showing a much more pronounced and rapid tendency towards reddening (Table 2). The literature reports that in jujube genotypes, the skin color changes from green to white and dark red tones during the ripening process; L*, a*, b*, hue°, and Chroma* values change within certain ranges, and colors can vary from reddish brown to purple, brown (Sulusoglu et al., 2014). This study, it was observed that fruit peel color changed significantly with ripening in genotypes of different sizes; in this context, the increase in the a* parameter reflecting the transition from green to red suggests that peel color transformation could be a practical indicator for monitoring fruit development.

Fruit weight, fruit diameter, and fruit length increased in both jujubes as the periods progressed. In the large-fruited jujube, fruit weight increased from 0.74 g in period t1 to 7.57 g in period t5, fruit diameter increased from 14.37 mm to 39.05 mm, and fruit length increased from 18.02 mm to 41.29 mm. In small-fruited jujube, fruit weight increased from 0.37 g to 1.25 g, fruit diameter increased from 11.92 mm to 19.97 mm, and fruit length increased from 13.13 mm to 19.44 mm. In large-fruited

jujube, fruit growth has occurred with a much higher potential in all dimensions compared to small-fruited jujube. This increase in fruit growth, particularly in large-fruited jujube, parallels the transition from green to red in skin color (increase in a^* value), suggesting that fruit development progresses simultaneously with physiological ripening processes. In small-fruited jujube, on the other hand, an earlier and faster reddening tendency was observed, while the increase in fruit size remained more limited, indicating that this genotype has a different ripening and growth strategy. Previous studies have reported that fruit diameter and fruit weight generally increase throughout the development process, while fruit length may slow down or even stop increasing between some consecutive dates (Ma et al., 2021). This study found that fruit weight (FWT), fruit diameter (FD), and fruit length (FL) increased as the seasons progressed in both large and small jujube trees. However, the slowdown or even stagnation in the increase of some

traits towards the end of the period (particularly the trend in FL during the t4-t5 periods) indicates that fruit size may approach saturation after a certain stage and is generally consistent with the literature (Ma et al., 2021). This situation indicates that fruit size should be evaluated not only in terms of final size but also in terms of changes in the timing and rate of growth. There is genetic diversity between wild and cultivated jujubes; cultivated fruits are generally larger, heavier, longer, and have a higher flesh/seed ratio than wild types (Şumalan et al., 2025). This study, the tendency of the large-fruited genotype to spread growth to later periods supports the superiority of cultivated material in terms of fruit size. Therefore, in selection and breeding efforts targeting high fruit size, it may be beneficial to conduct a comprehensive evaluation based not only on final fruit size/weight but also on growth curve parameters and measurable indicators such as SPAD, leaf area, and a^* .

Table 1. Chlorophyll content leaf area, and leaf color parameters in large and small-fruited jujube according to developmental (t1–t5)

Period	Size	Traits						
		SPAD	Leaf Area	L*	a^*	b^*	Chroma	hue°
t1	Large	41.38±3.81 ^a	61.38±9.33 ^a	38.19±3.32 ^a	6.83±3.62 ^a	65.83±5.73 ^a	66.31±5.36 ^a	83.69±3.63 ^a
	Small	41.85±2.59 ^a	49.97±9.00 ^b	37.29±4.12 ^a	8.22±5.70 ^a	64.48±7.02 ^a	65.44±5.19 ^a	82.40±7.28 ^a
t2	Large	42.50±3.31 ^a	63.29±9.08 ^a	35.70±2.53 ^b	10.51±3.20 ^a	61.53±4.36 ^b	62.54±3.72 ^b	80.10±3.65 ^b
	Small	41.96±5.68 ^a	53.42±9.46 ^b	37.26±3.00 ^a	8.22±3.65 ^b	64.17±5.22 ^a	64.82±4.68 ^a	82.33±3.99 ^a
t3	Large	43.26±3.86 ^a	82.13±9.54 ^a	33.26±3.01 ^b	13.62±4.16 ^a	57.42±5.21 ^b	59.23±3.88 ^b	76.40±5.46 ^b
	Small	41.06±3.90 ^b	61.46±10.35 ^b	36.68±2.76 ^a	9.01±2.94 ^b	63.22±4.75 ^a	64.00±4.36 ^a	81.60±3.35 ^a
t4	Large	45.05±5.05 ^a	81.33±10.90 ^a	32.34±2.51 ^b	14.72±3.33 ^a	55.79±4.33 ^b	57.83±3.30 ^b	74.93±4.36 ^b
	Small	44.13±4.06 ^a	73.12±14.89 ^b	37.54±2.88 ^a	7.78±3.17 ^b	64.97±5.25 ^a	65.53±4.85 ^a	82.92±3.33 ^a
t5	Large	48.90±5.71 ^a	92.18±13.70 ^a	30.14±4.81 ^b	19.22±6.85 ^a	51.81±8.05 ^b	56.01±5.12 ^b	69.07±9.66 ^b
	Small	42.69±4.29 ^b	85.09±12.46 ^b	35.84±6.73 ^a	9.59±3.16 ^b	62.61±5.62 ^a	63.59±4.97 ^a	81.05±3.43 ^a
ANOVA	<i>df</i>	(F-values)						
Size	1	8.28**	38.50**	20.60**	45.78**	38.82**	38.44**	41.28**
Period	4	6.65**	44.84**	4.46**	8.97**	6.18**	5.91**	7.70**
Size* Period	4	1.88	4.31**	4.21**	9.42**	7.07**	6.44**	8.18**

Different lowercase letters (a, b) within the same column indicate significant differences between sizes ($P < 0.05$) by Tukey's HSD test. Two-way ANOVA results show the significance levels for Size, Period, and their interaction (Size×Period).

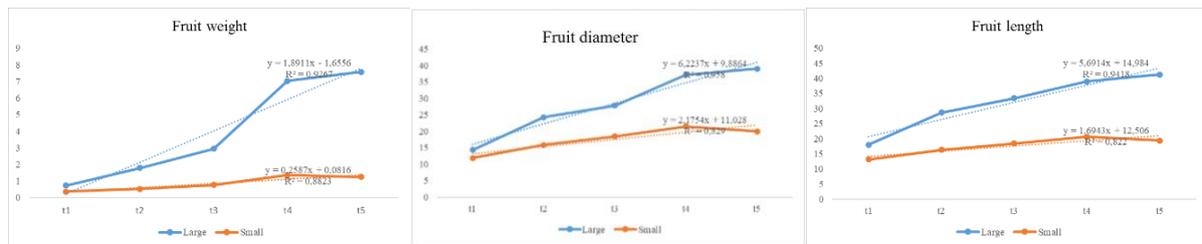


Figure 2. Growth curve of fruit weight, fruit diameter, and fruit length in large and small-fruited jujube.

Jujube is reported to have eight main phenological stages, starting from bud growth and including fruit ripening (Sapkota et al., 2020). Determining the correct harvest time is crucial for increasing fruit yield and quality. Therefore, a good understanding of the fruit development process plays a critical role in determining the appropriate harvest time. Indeed, the most suitable

period for harvesting jujube fruit for consumption is when the fruit is at full maturity. When the fruits have reached sufficient size and the appearance specific to the variety, they can be harvested at the optimal maturity level to meet market requirements and minimize the risk of spoilage (Krishna et al., 2016). During ripening, the fruit color changes from green to yellow and chocolate

brown (Shahrajabian et al., 2020). It is also reported that the fruit can turn dark reddish-brown within approximately four to six weeks after the first color change (Sapkota et al., 2020). Following this process, the fruits begin to dry and wrinkle, reaching the optimum harvest stage approximately 10–12 weeks after fruit set, usually between mid- and late September (Sapkota et al., 2020). This study revealed that FW, FD, and FL data showed that fruit growth in both genotypes followed a sigmoid dynamic throughout five developmental stages (t1–t5). In terms of periods, t1–t2 represents the initial phase of growth, t2–t3 the phase of accelerated growth, and t4–t5 the phase of transition to a stable trend. It shows that growth accelerates particularly in t2–t3 stages and slows down in t4–t5 stages in large-fruited jujubes. In contrast, it indicates that in the small-fruited population, growth reaches its maximum rate near t1 and enters a stable trend earlier in subsequent stages. The significantly higher fruit size in the large-fruited genotype and the approximately twofold superiority in size compared to the small-fruited population confirm the fruit size potential of the cultivated material. Similarly, Ma et al. (2021) reported that the time-dependent changes in fruit length, width, and weight of

jujube could be successfully modeled using logistic growth curves. However, it has also been reported that some jujube varieties can exhibit a double sigmoid growth curve; a double sigmoid growth pattern in terms of fruit diameter and fresh weight has been reported in *Ziziphus jujuba* Mill. cv. Changhong. However, it should be considered that the growth pattern may vary depending on the variety and ecology (Lu et al., 2012). In a comprehensive study by Pei et al. (2020), the molecular developmental processes of pear, peach, and strawberry fruits were investigated. In this study, it was determined that pear fruits exhibited single sigmoid growth, whereas peach and strawberry fruits showed double sigmoid growth. Furthermore, it was shown that both growth patterns resulted from cell expansion rather than cell division. In contrast, similar molecular studies on jujube fruit are not yet available in the literature. Investigating the molecular mechanisms of the developmental processes of jujube fruit will provide a better understanding of fruit growth dynamics and will make significant contributions to genetic improvement studies. Therefore, conducting comprehensive studies at the molecular level on jujube and increasing research in this field are of great importance in the future.

Table 2. Fruit skin color parameters (L*, a*, b*, Chroma*, hue°) and fruit weight, fruit diameter, and fruit length according to developmental stages (t1–t5) in large and small-fruited jujubes

Period	Size	Traits				
		L*	a*	b*	Chroma	Hue°
t1	Large	54.56±2.67 ^b	-3.73±0.97 ^a	91.72±6.27 ^a	91.75±6.24 ^a	92.33±2.17 ^a
	Small	58.81±2.34 ^a	-5.75±0.74 ^b	89.07±10.76 ^a	89.27±10.72 ^a	93.06±4.72 ^a
t2	Large	58.76±2.76 ^b	-4.41±0.96 ^a	78.39±13.20 ^a	78.50±13.17 ^a	108.35±95.11 ^a
	Small	60.60±2.23 ^a	-5.45±1.61 ^b	81.32±13.55 ^a	81.44±13.49 ^a	94.24±1.14 ^a
t3	Large	59.79±4.03 ^a	-4.31±0.96 ^a	97.46±147.11 ^a	75.02±16.92 ^a	93.42±1.20 ^a
	Small	61.06±3.13 ^a	-4.68±0.97 ^a	74.20±14.36 ^a	74.34±14.33 ^a	93.73±1.13 ^a
t4	Large	67.41±4.62 ^a	-2.38±1.66 ^a	45.94±11.38 ^b	46.08±11.31 ^b	93.31±2.17 ^a
	Small	63.71±5.62 ^b	-1.61±5.57 ^a	55.81±13.63 ^a	56.21±13.59 ^a	92.11±4.73 ^a
t5	Large	68.76±8.38 ^a	3.54±6.89 ^b	40.52±13.32 ^b	40.92±14.07 ^b	85.04±10.15 ^a
	Small	39.08±14.09 ^b	29.94±15.13 ^a	55.93±10.61 ^a	65.31±9.80 ^a	62.62±15.08 ^b
ANOVA	df	(F-values)				
Size	1	26.72**	32.81**	3.72	9.40**	13.79**
Period	4	17.34**	95.92**	78.02**	68.95**	63.57**
Size* Period	4	42.04**	34.62**	5.14**	9.38**	11.33**

Different lowercase letters (a, b) within the same column indicate significant differences between sizes (P<0.05) by Tukey's HSD test. Two-way ANOVA results show the significance levels for Size, Period, and their interaction (Size×Period).

3.2. Multivariate Correlation Analysis

According to multivariate correlation analysis, strong relationships were determined between FW, FD, FL, and physiological and color characteristics (Figure 3). Very strong positive correlations were found between SPAD and yield traits, specifically with FW ($r=0.89$, $P=0.0007$), FD ($r=0.86$, $P=0.0014$), and FL ($r=0.80$, $P=0.0052$). Similarly, LA showed strong positive correlations with FW ($r=0.74$, $P=0.0142$), FD ($r=0.81$, $P=0.0044$), and FL ($r=0.77$, $P=0.0094$). These results indicate that as leaf chlorophyll content and leaf area increase, fruit weight

and size increase accordingly. Furthermore, a significant positive correlation was observed between SPAD and LA ($r=0.75$, $P=0.0118$).

In terms of color characteristics, the a^*/l component showed extremely strong positive correlations with FW, FD, and FL ($r = 0.93$; $P<0.001$), indicating that increases in a^*/l are accompanied by heavier, larger fruits. In contrast, the L^*/l and b^*/l parameters in the leaves showed very strong negative correlations with FW, FD and FL ($r = -0.94$, $P<0.001$). Regarding fruit color measurements, L^* showed moderate positive correlations with FW ($r=0.55$,

P=0.0412), FD ($r=0.52$, $P=0.0488$), and FL ($r=0.51$, $P=0.0495$). The $b*f$ values measured in the fruits showed moderate negative correlations with FW ($r=-0.67$, $P=0.0112$) and FD ($r=-0.66$, $P=0.0134$).

Fruit length, fruit width, seed length, seed width, and seed weight are known to have significant effects on fruit weight (Khadivi, 2023). Indeed, in our study, the high

fruit weight values of the large-fruited genotype are explained by the combination of these morphological characteristics. Ma et al. (2021) highlighted strong relationships among components of fruit size. However, this study reveals that fruit growth should be monitored not only through morphological measurements but also using SPAD readings, leaf area, and color values.

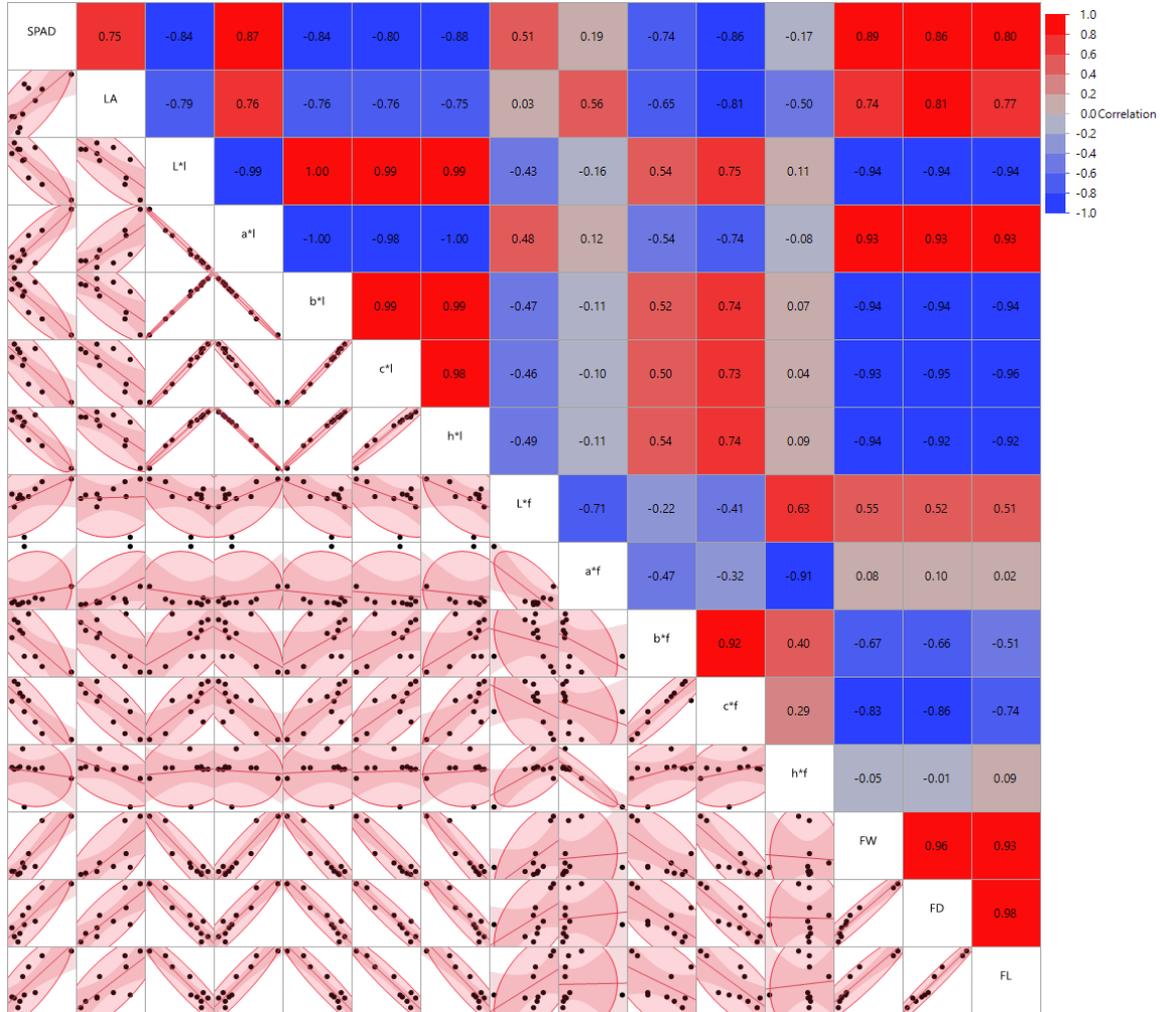


Figure 3. Correlation matrix between fruit weight, fruit diameter, fruit length, leaf characteristics (SPAD, leaf area), and color parameters. The subscripts 'l' and 'f' denote leaf and fruit characteristics, respectively.

4. Conclusion

This study investigated the fruit development dynamics and the physiological and color characteristics of the leaves of two jujube tree sizes (large and small) grown under similar conditions in the Çivril district of Denizli province. Measurements taken at five different developmental stages showed that large-fruited jujubes had a significant genetic superiority in terms of fruit weight, diameter, and length compared to the small-fruited population. While the maximum growth rate in small-fruited jujubes occurred in the early stages, this was spread over later stages in large-fruited jujubes. Rapid growth was observed in large-fruited jujubes during periods t1-t2 and especially t2-t3, while the growth rate slowed down and almost stopped during

periods t3-t4 and t4-t5. In small-fruited jujubes, growth was slower and more limited, showing little growth in periods t1-t2, slightly accelerating in periods t2-t3, and then slowing down, stopping, and showing very little increase during periods t3-t4 and t4-t5. SPAD values and leaf area increased throughout development in both genotypes, but remained consistently higher in large-fruited jujube. Correlation analyses revealed strong positive associations between fruit size and leaf characteristics (especially SPAD, LA, and a*). These results demonstrate successful characterization of fruit growth in jujube, and that SPAD, leaf area, and fruit a* are important indicators for fruit size and ripening performance. The study provides valuable information for selection and breeding strategies to improve fruit quality in jujube.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	T.B.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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