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Genetic Diversity Analysis of Phenotypic Traits in Jujube Germplasm Resources

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Abstract

To explore the phenotypic diversity of jujube germplasm resources and identify superior genotypes, this study systematically evaluated 150 jujube accessions. Multiple organ-related traits—including branches, thorns, bearing shoots, leaves, flowers, and fruits—were investigated. A comprehensive, multidimensional analysis was conducted to assess phenotypic variation and diversity. The results provide valuable insights for germplasm conservation and the selection of elite jujube varieties. The results showed that the variation coefficient of 18 quantitative traits ranged from 5.07% to 21.43%; the variation coefficient of fruit quality traits ranged from 4.25% to 13.48%; and the results of the cluster analysis showed that the germplasm resources were classified into three categories according to the quantitative traits and four categories according to the fruit quality traits. Principal component analysis extracted six significant components for fruit quality traits, accounting for 86.88% of the total variance. Based on the comprehensive evaluation of factor analysis, Sanlengzao, Linyilajiaozao, Zan 2, Jinmanguo, and Jing 39 performed well and ranked high in the comprehensive ranking, which can be used as an important reference for the evaluation of jujube germplasm resources and the selection and breeding of good varieties.

Keywords: germplasm resources; phenotypic traits; special germplasm

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1. Introduction

Jujube (*Ziziphus jujuba* Mill.) belongs to the genus *Ziziphus* in the *Rhamnaceae* family and is one of the important economic tree species in China, with extremely high nutritional value and medicinal value [1]. China has abundant genetic resources of jujube, which are widely distributed. However, due to long-term natural selection and artificial cultivation, different genetic resources exhibit significant diversity in phenotypic traits such as branches, leaves, flowers, and fruits. Variation in phenotypic traits is an important reflection of the genetic diversity of germplasm resources and the basis of good seed selection and variety improvement [2,3]. At the same time, it is the result of the joint action of genetic diversity and environmental factors, which can intuitively reflect the genetic variation and adaptive capacity of species.

In-depth studies can be conducted to understand the genetic diversity, cultivation adaptability, and potential for varietal improvement of jujube germplasm resources [4]. For leaf traits, the correlation between leaf chromatic attributes and physiological parameters has been comprehensively elucidated. The determination and description of leaf trait diversity has been reported to provide new reference indexes for germplasm identification and utilisation, as well as classification, and can also be used as a basis for exploring the affinities among species and varieties [5,6]. In their study on the diversity of jujube germplasm fruit texture traits, Suwanlong et al. [7] identified four key parameters—flesh hardness, peel puncture strength, flesh firmness, and peel brittleness—as critical indicators for evaluating jujube fruit texture quality. These traits provide a robust foundation for assessing and classifying textural characteristics in jujube germplasm. Xuan et al. [8] demonstrated that triploid jujube progeny exhibit significant advantages over diploids in both nutrient organs and fruit-related traits. Furthermore, a pronounced divergence was observed between domesticated and wild hairy leaf jujube in key agronomic characteristics. Domesticated varieties displayed larger leaves, shorter thorns, and fruits with enhanced size, flesh thickness, and sweetness compared to their wild counterparts [9]. Numerous studies have systematically screened germplasm based on fruit quality traits to identify elite cultivars [10–12]. Such evaluations are critical for clarifying phenotypic variation, elucidating the breeding value of individual accessions, and providing a foundation for genetic improvement, conservation, and sustainable utilisation of jujube germplasm resources [13,14]. Although numerous studies have investigated phenotypic diversity in jujube germplasm resources, current research remains limited in several aspects. Most existing studies focus on single organ systems, lacking comprehensive analyses of integrated morphological characteristics across multiple organs, including branches, thorns, bearing shoots, and flowers. To address these gaps, this study will systematically evaluate the phenotypic diversity of 150 jujube germplasm accessions from southern Xinjiang, characterising their growth and morphological traits. The findings will provide valuable insights for jujube germplasm utilisation, conservation, and breeding innovation.

2. Materials and Methods

2.1. Experimental Materials

The experimental materials were 150 jujube resources, including 139 introduced varieties and 11 progenies of different varieties, preserved in the jujube germplasm resource nursery of Tarim University in the Alar region of Xinjiang (81°17′ 41.61″ E, 40°32′ 23.50″ N). The varieties come from Beijing, Gansu, Guangdong, Guizhou, Hebei, Henan, Shandong, Shaanxi, Hunan, Jiangsu, Liaoning, Ningxia, Shanxi, Tianjin, Xinjiang, and Yunnan. The trees are robust, stable in traits, basically uniform in growth, and free of pests and diseases. The spacing between plants is 2 m × 3 m, with conventional management. The jujube offspring were selected through seedling cultivation and were all 10 years old.

2.2. Experimental Methods

2.2.1. Botanical Trait Investigation and Sampling Methods

Observations were made on branches (8 traits), thorns (2 traits), bearing shoots (2 traits), leaves (11 traits), petioles (4 traits), flowers (3 traits), fruits (31 traits), and kernels (3 traits) of jujube germplasm resources. Jujube palms with normal development and free of pests and diseases were selected and investigated according to the Specification and Data "Standard for the Germplasm Resources of Chinese jujube" [15]. The investigation began in 2023.

The robust secondary branches in the lower middle part of the canopy periphery were selected, and the length of the secondary branches, the length of the fruiting spurs, and the

spacing between the nodes of the secondary branches were measured using a tape measure with 9 repetitions (Dexin Metal Products Co., Ltd., Huangshan, China).

The straight and curved thorns on nodes 1 to 5 of the secondary branches were selected and measured using a vernier calliper for 9 repetitions (Shanghai Deyixing Tools Co., Ltd., Shanghai, China). During the blooming period, we observed the colour of honeydew discs, measured the size of honeydew discs and the size of flowers using vernier callipers for 10 repetitions, and calculated the average value of the honeydew discs. A total of 30 uniformly grown and mature leaves were selected from the fruiting spurs in the middle of the branches from late July to early August, and we observed the colour of leaves, shape of leaves, shape of leaf bases, shape of leaf tips, shape of leaf margins, state of leaves, leaf lustre, and the index of leaf shape, and brought them back to the laboratory to measure the length, width, perimeter, and area of the leaves and petioles using the Wansen LA-S Plant Image Analyser (TMA1600). (Hangzhou Wan Shen Testing Technology Co., Ltd., Hangzhou, China).

2.2.2. Fruit Quality Sampling and Determination

From September to October 2023, we determined external quality: During the period of fruit ripening, 30 randomly selected fruits of similar size and free of pests and diseases were taken, and the fruits were weighed on the electronic balance, and the weight of single fruit was recorded (Shanghai Pohai Instrument Company, Shanghai, China). The longitudinal diameter and transverse diameter of the fruit were measured by vernier callipers (Shanghai Deyixing Tools Co., Ltd., Shanghai, China). and photographed, and the kernel shells were cut to observe the presence or absence of the kernel shell and kernel type. All materials were sent back to the laboratory on the day of harvest for sample processing and determination of various indices. After the measurements were completed, the fruit was peeled and deveined and stored in a refrigerator at −20 °C to facilitate the determination of the intrinsic quality at a later stage.

Determination of intrinsic quality was as follows: soluble solids content was measured using a refractometer; (ATAGO Co., Ltd., Tokyo, Japan) soluble sugars content was determined using the anthrone colourimetric method; titratable acid content was determined using the acid–base titration method; vitamin C content was measured using the molybdenum blue colourimetric method; total flavonoids content was measured using the aluminium nitrate–sodium nitrite colourimetric method; total phenols content was determined using the Folin–Ciocalteu colourimetric method; and protein content was measured using the Coomassie Brilliant Blue method.

2.3. Data Processing

Data statistics and processing were performed using Excel 2019 software, and standard deviation and coefficient of variation, principal component analysis, and factor analysis were calculated using SPSS 25.0 (SPSS Institute Inc., Armonk, NY, USA).and DPS (ADO Inc., Hangzhou, China).

Genetic diversity index calculation: Shannon's information index (H′), $H' = -\Sigma Pi \times \ln Pi$, was used for the genetic diversity of each trait, where Pi represents the percentage of the i-th grade trait in the total number of copies.

Cluster analysis and mapping were conducted with Chiplot (https://www.chiplot.online/index.html accessed on 24 August 2025).

3. Results

3.1. Analysis of Botanical Trait Surveys

3.1.1. Statistical Comparison of Descriptive Traits

The frequencies of 35 descriptive traits in 150 jujube germplasm resources were counted, and the corresponding genetic diversity index was calculated. As shown in Table 1, there were 11 types of fruit shapes (Figure 1), with the proportions of globose and oblong globose being similar, and the millstone and teapot shapes accounting for at least 0.7% and 0.6%, respectively. The shape of the fruit shoulder was divided into flat and concave (74.7% and 25.3%). The fruit flavour was divided into five categories, of which sweetness accounted for 52%, extremely sweet accounted for 4%, sweet and sour accounted for 16.7%, and sweet and sour accounted for 16.7%. The flesh texture was crispy and dense, 50.7% and 30.7%, respectively. The flesh thickness was mostly moderate, accounting for 62%; the juice of the pulp was mainly moderate, 50.7%; and secondary branch curvature in the special bending angle of the Longzao accounted for 0.7%. The shape of the leaf margin appeared mostly in an inclined shape, at 52%, with the rarest being the heart shape and the cut shape, at 2% and 1.3%, respectively (Figure 2). The leaf tip shape was mainly blunt tine, with rapid tine and acute-recessed accounting for the same proportion of 32%. There were two types of margin shapes: sawtooth, 31.3%, and flat, 68.7%. Among the kernel traits of jujube, the stone shapes were classified into four categories, with ellipsoid being the most prevalent, spindle shape being the second most prevalent, and globose being the least prevalent, at 1.3% (Figure 3). Among the floral traits, nectar disc colour was classified into three categories: yellowish green (56.7%), whitish yellow (29.3%), and milky (14%). From the results of the genetic diversity index, the diversity index of descriptive traits in jujube germplasm ranged from 4.84 to 6.92, of which the highest diversity index was 6.92 for stigma status, and the lowest diversity indexes were 4.84 and 4.88 for leaf margin and fruit shape, while fruit flavour and stigma status exceeded the maximum value of the diversity index of 5.01.

Table 1. Quality trait frequencies and genetic diversity indices.

Descriptive Traits	Trait Characteristics	Frequency (%)	H′	Descriptive Traits	Trait Characteristics	Frequency (%)	H′
type of bark dry cracking	strip	99.3	5.01	depth of stalk cavity	shallow	14.1	4.97
	lumpy	0.7			intermediate	66.7	
colour of extension shoot	yellow brown	4.7	4.96		deep	18.1	
	fusco rufous	40.7		width of stalk cavity	narrow	8.7	4.99
	taupe	10			intermediate	78.7	
	purple brown	36			broad	12.7	
	light grey	5.3		lubricity of fruit skin	smooth	93.3	4.96
	celadon	3.3			rough	2.7	
wax layer on the surface of extension shoot	dense	34	4.95		raised	4	
	sparse	57.3		size of fruit dot	small	10.7	4.97
	none	8.7			intermediate	50.7	
curvature degree of secondary shoot	≤15°	24.7	4.95		large	38.7	
	15°~30°	60.7		density of Fruit dot	sparse	51.3	4.92
	≥30°	14			intermediate	33.3	
	0°	0.7			dense	15.3	
leaf lustre	dull	4.7	4.99	fruit size	small	4.7	4.96
	glossier	85.3			medium-small	17.3	
	glossy	10			medium	41.3	
leaf colour	light green	9.3	4.97		medium-large	28.7	
	green	57.3			large	8	
	dark green	33.3			extra-large	0	

Table 1. *Cont.*

Descriptive Traits	Trait Characteristics	Frequency (%)	H′	Descriptive Traits	Trait Characteristics	Frequency (%)	H′
leaf state	curving	18	4.97	fruit colour	light red	1.3	4.97
	flat	68.7			red	83.3	
	back curving	13.3			mauve	4.7	
leaf shape	ellipse	27.3	4.94		reddish brown	10	
	ovoid	44			orange	0.7	
	egg-oviform	28.7		colour of fruit flesh	white	0.7	4.97
shape of leaf margin	round shape	35.3	4.84		light green	92.7	
	heart shape	2			green	6.7	
	cut shape	1.3		thickness of fruit skin	thin	6	4.98
	round-cuneiform	9.3			intermediate	52	
	inclination shape	52			thick	42	
Shape of leaf apex	sharp tine	10	4.97	fruit flavour	sour	0.7	5.05
	blunt tine	55.3			sweet-sour	26.7	
	rapid tine	32			sour-sweet	16.7	
	acute-recessed	32			sweet	52	
shape of leaf margin	minute sawtooth	31.3	4.97		extremely sweet	4	
	bicrenate	68.7		texture of fruit flesh	loose	8.7	4.96
stigma state	keep	4.7	6.92		crisp	50.7	
	remnant	93.3			intermediate	30.7	
	desquamate	2			compact	10	
sepal attitude	keep	0.7	4.99	coarseness of fruit flesh	delicate	18.7	4.96
	remnant	22			intermediate	62	
	desquamate	77.3			coarse	19.3	
fruit uniformity	same size	14	4.98	juice of fruit flesh	lack	36	4.96
	relatively same size	72			medium	50.7	
	different size	14			rich	13.3	
fruit cracking	yes	6.7	4.97	state of stone shell	contain	97.3	5.01
	rich	4.7			remnant	1.3	
	slight	39.3			none	1.3	
	no	49.3		stone shape	globose	1.3	4.96
fruit shape	globose	2.7	4.88		ellipse	44	
	oblate	27.3			spindly	28	
	oblong globose	21.3			inverted spindly	25.3	
	ovoid	13.3		kernel size	small	4	4.96
	obovate	10.7			medium	44	
	coniform	4.7			medium-large	44.7	
	cylinder	16			large	5.3	
	millstone	0.7		colour of flower disc	milky	14	4.96
	flat cylinder	2.7			whitish yellow	29.3	
	teapot shape	0.6			yellowish green	56.7	
shape of fruit shoulder	flat	74.7	4.96	shape of fruit top	concave	40	4.91
	convex	25.3			flat	47.3	
					tine	6.7	
					convex	6	



Figure 1. Fruit shape diversity. (**a**) Globose, suanzao. (**b**) Oblate, daguosuanpan. (**c**) Ovoid, shanghaibaipu. (**d**) Oblongglobose, linxianyazao. (**e**) Obvate, jun. (**f**) Cylinder, zhongzao. (**g**) Coniform, yueguang. (**h**) Millstone, mopanzao. (**i**) Flat cylinder, kulinzao. (**j**) Teapot, chahuzao. (**k**) Gourd-shaped, huluzao.



(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 2. Leaf margin diversity. (**a**) Round shape. (**b**) Heart shape. (**c**) Cut shape. (**d**) Round-cuneiform. (**e**) Inclination shape.



(**a**) (**b**) (**c**) (**d**)

Figure 3. Stone shape diversity. (**a**) Globose. (**b**) Ellipse. (**c**) Spindly. (**d**) Inverted spindly.

3.1.2. Statistical Comparison of Quantitative Traits

Quantitative traits are generally susceptible to changes in habitat, cultivation, climate, and other environmental influences, but the large sample size of this study can also indicate the genetic diversity of the species. In the diversity comparison of 18 quantitative traits of jujube germplasm resources, the coefficients of variation in each trait varied considerably from each other, as shown in Table 2, below, with an average coefficient of variation of 15.02 per cent. The coefficient of variation for the number of fruit-bearing spurs and petiole width was the highest at 20.37 and 21.43 percent, respectively, and the range of variation ranged from 1.1 to 6.67 (units) and from 0.87 to 2.45 (mm), respectively. This was followed by the number of mother-bearing shoots and petiole length at 18.54 and 18.92 percent, respectively, with variability ranging from three to twelve (nodes) and 1.77 to 11.06 (mm), respectively. The smallest variation was in flower size at 5.07 percent, with a range of variation between 4.19 and 7.39 (mm), and another trait of the flower also had a smaller coefficient of variation of 7.35 percent, with a range of variation between 2.19 and 3.66 (mm). It shows that the genetic traits of the flowering organs of jujube trees have become more stable in the long-term evolution, and the fluctuation of the influence of the external environment is smaller. The coefficients of variation in leaf circumference and leaf length were also small, 11.31% and 9.46%, respectively, and the magnitude of variation ranged from 81.93 to 262.36 (mm) and 30.34 to 91.75 (mm), respectively.

Table 2. Statistics and coefficients of variation of 18 quantitative traits of 150 jujube germplasm resources.

Serial Number	Quantitative Trait	Min	Max	Range	Mean	S	CV
1	number of secondary shoot nodes (units)	3	12	9	6.58	1.22	18.54
2	length of secondary shoot (cm)	3.13	12.71	9.58	5.17	0.95	18.37
3	number of mother-bearing shoots(units)	3	12	9	6.19	0.97	15.67
4	number of fruit-bearing spurs (units)	1.1	6.67	5.57	2.11	0.43	20.37
5	length of bearing shoot (cm)	9.37	42.1	32.73	18.64	2.61	14.00
6	number of leaves on bearing shoot (units)	6.67	41.1	34.73	10.66	1.72	16.13
7	stab straight up length (mm)	2.97	27.95	24.98	10.62	1.61	15.16
8	thorn length (mm)	1.73	7.03	5.3	3.29	0.5	15.2
9	size of opened flower (mm)	4.19	7.39	3.2	5.71	0.29	5.07
10	size of flower disc (mm)	2.19	3.66	1.47	2.72	0.2	7.35

Table 2. *Cont.*

Serial Number	Quantitative Trait	Min	Max	Range	Mean	S	CV
11	blade length (mm)	30.34	91.75	61.41	62.35	5.9	9.46
12	blade width (mm)	15.59	52.58	36.99	31.56	3.23	10.23
13	blade area (mm^2)	666.9	2879.59	2212.1	1385.71	245.5	17.72
14	blade circumference (mm)	81.93	262.36	180.43	147.77	16.71	11.31
15	petiole length (mm)	1.77	11.06	9.29	5.02	0.95	18.92
16	petiole width (mm)	0.78	2.45	1.67	1.4	0.3	21.43
17	petiole circumference (mm)	4.7	22.19	17.49	13.5	2.33	17.26
18	petiole area (mm^2)	0.69	9.24	8.55	3.96	0.72	18.18

3.2. Analysis of Fruit Quality Trait Survey

Genetic diversity analysis of fruit quality traits of jujube germplasm was carried out, as shown in Table 3 below. The coefficient of variation for total flavonoid content was the largest at 13.48%, and the range of variation was from 0.95 mg/g to 3.25 mg/g; the coefficients of variation for the contents of single-fruit weight, titratable acid, and soluble sugar were next to the highest at 12.87%, 11.07%, and 10.37%, respectively; whereas the longitudinal diameter of the fruit, the transverse diameter of the fruit, fruit shape index, and soluble solids content had smaller coefficients of variation of 5.08%, 5.25%, 5.3%, and 4.25%, respectively. The ranges of variation were 16.23–56.12%, 15.57–42.84%, 0.92–2.09% and 19.77–31.93%, respectively.

Table 3. Statistics of 11 fruit quality quantitative traits of 150 jujube germplasm resources.

Fruit Quality Traits	Min	Max	Mean	S	CV	Diversity Index
single-fruit weight (g)	2.05	39.29	17.09	2.2	12.87	4.92
longitudinal diameter of fruit (mm)	16.23	56.12	38.42	1.95	5.08	4.99
transverse diameter of the fruit (mm)	15.57	42.84	29.72	1.56	5.25	4.99
fruit shape index	0.92	2.09	1.32	0.07	5.3	4.99
soluble solids content (%)	19.77	31.93	26.37	1.12	4.25	5.01
soluble sugar content (%)	9.84	39.93	24.66	2.52	10.37	4.99
titratable acid (%)	0.2	1.51	0.35	0.04	11.07	4.96
total flavonoids (mg/g)	0.95	3.25	1.5	0.2	13.48	4.97
total phenol (mg/g)	2.67	9.42	5.62	0.55	10.13	4.96
protein content(mg/g)	0.95	2.64	1.51	0.12	8.29	4.94
vitamin C content (mg/g)	2.86	6.99	4.59	0.26	5.71	4.99

3.3. Cluster Analysis

3.3.1. Cluster Analysis of Morphological Traits

Morphological traits were analysed in clusters as shown in Figure 4a, where all the materials were classified into three classes; class I included 14 materials. It is characterised by medium-sized leaf blades, small leaf circumference, shorter petioles, and longer straight spiny thorns and bearing shoots. Class II included 68 materials characterised by a small petiole area, elongated leaf blades, a smaller number of mother-bearing shoots, and secondary shoot nodes. Class III included 68 materials characterised by a higher number of bearing shoot leaves and longer bearing shoots.

3.3.2. Cluster Analysis of Fruit Quality Traits

The clustering results of the fruit quality traits of 150 jujube germplasm resources are shown in Figure 4b below, with all indicators clustered into four classes. Class I contains only suanzao, which is characterised by a smaller fruit appearance, higher acidity, and lower sugar content. Class II includes 36 materials, which are characterised by larger fruit size and lower soluble solids, soluble sugar, and total phenol content. Class III includes 33 materials, which are characterised by the long-fruit type and higher total phenol content. Class IV is the largest group, including up to 70 materials, which is characterised by smaller

fruits, higher soluble sugar content, soluble solids, vitamin C content, etc., and better performance in a number of indicators.



(**a**) (**b**)

Figure 4. Cluster analysis chart. (**a**) Morphological shape clustering analysis diagram. (**b**) Cluster analysis of fruit quality and other traits.

3.4. Comprehensive Evaluation

3.4.1. Principal Component Analysis

The raw data were examined by Bartlett's sphericity test for 11 quantitative traits of fruit quality through SPSS. The results showed that the KMO measure was 0.447 (<0.6), the accompanying probability of the sphericity test was sig = 0.001 (<0.01, extremely significant), and Bartlett's test statistic for sphericity was 864.887, which shows that this data is suitable for the factor analysis method [15].

The results are as follows: as can be seen from Table 4, the cumulative rate in the first principal component is 31.41% until the sixth principal component reaches 86.88%, so these six principal components can reflect most of the information. The variance contribution rate of the first principal component was 31.41%, mainly reflecting fruit soluble sugar, single fruit weight, and longitudinal and transverse diameters. The variance contribution rate of the second principal component was 14.76%, mainly reflecting fruit shape index; the variance contribution rate of the third principal component was 11.75%, mainly reflecting fruit vitamin C, titratable acid; the variance contribution rate of the fourth principal component was 10.42%, mainly reflecting fruit total phenol; the variance contribution rate of the fifth principal component was 9.73%, mainly reflecting the proteins and total flavonoids of the fruit; and the variance contribution rate of the sixth principal component was 8.79%, mainly reflecting the soluble solids of the fruit.

Table 4. Principal component analysis of fruit quality traits.

Fruit Quality	Principal Component					
	1	**2**	**3**	**4**	**5**	**6**
soluble sugar	0.98	0.14	−0.05	−0.04	−0.01	0.001
titratable acid	−0.11	−0.12	0.71	−0.43	−0.01	0.17
soluble solids	−0.04	0.07	0.02	0.09	−0.002	0.94
total flavonoids	−0.05	0.11	0.28	0.24	0.67	−0.33
total phenol	−0.1	−0.11	−0.02	0.9	−0.02	0.1
protein	−0.01	−0.12	−0.21	−0.17	0.82	0.17
vitamin C	−0.02	0.11	0.81	0.14	−0.02	−0.09
single-fruit weight	0.95	−0.18	−0.02	−0.05	−0.001	−0.07
longitudinal diameter of fruit	0.84	0.52	−0.01	−0.06	−0.03	0.03
transverse diameter of the fruit	0.9	−0.41	−0.09	0.07	0.01	−0.04
fruit shape index	−0.08	0.98	0.04	−0.08	−0.04	0.06
eigenvalue	3.46	1.62	1.29	1.15	1.07	0.97
contribution rate	31.41	14.76	11.76	10.42	9.74	8.79
cumulative contribution	31.41	46.17	57.93	68.35	78.08	86.88

3.4.2. Factor Analysis

According to the results of the principal component analysis of fruit quality for factor analysis, a total of six factors were identified, respectively, to calculate the weight value for evaluation, with the eigenvectors as the weights, calculated weight values of 0.36, 0.17, 0.14, 0.12, 0.11, 0.1, respectively, for the evaluation of the selection of the top ten ranking of the germplasm. The results are shown in Table 5, with the top 20 varieties being the following: sanlengzao, linyilajiaozao, zan 2, jinmangguo, jing 39, jinzao 1, damuzao, hamazao, ningyanglingzao, longzao, jinai 1, jinai 4, jun 2, xuanchengyuanzao, dabailing, mx5n3, jingudazao, linxianheyizao, shandongpingguo, zan 1.

Table 5. Comprehensive ranking of jujube germplasm resources.

Variety	Score	Ranking	Variety	Score	Ranking
sanlengzao	0.75	1	jiuzhuangwozao	0.50	76
linyilajiaozao	0.71	2	xinzhenglingzao	0.50	77
zan 2	0.70	3	tengzhoutangzao	0.50	78
jinmangguo	0.69	4	xiangzao	0.50	79
jing 39	0.68	5	tailihong	0.49	80
jinzao 1	0.68	6	yucituanzao	0.49	81
damuzao	0.66	7	s-182	0.49	82
hamazao	0.66	8	xiangfenyuanzao	0.49	83
ningyanglingzao	0.66	9	dalilinglingzao	0.49	84
longzao	0.65	10	jinkang 2	0.49	85
jinai 1	0.64	11	xiangfenmuzao	0.49	86
jinai 4	0.64	12	yongchengchanghong	0.49	87
jun 2	0.63	13	xiaozizao	0.49	88
xuanchengyuanzao	0.63	14	chahuzao	0.48	89
dabailing	0.63	15	hutouhuizao	0.48	90
mx5n3	0.62	16	mx4b2	0.48	91
jingudazao	0.62	17	shanxiniunaicui	0.48	92
linxianheyizao	0.62	18	henanyouxi 1	0.47	93
shandongpingguo	0.61	19	bianhesuan	0.47	94
zan 1	0.61	20	xinzhenghong 3	0.47	95
yuanlingxin 1 hao	0.61	21	houtouzao	0.47	96
lajiaozao	0.61	22	wuhehong	0.47	97
jinai 3	0.60	23	jidanzao	0.47	98
bayangzao	0.60	24	linzexiaozao	0.47	99
ningyangyuanhongzao	0.60	25	luodihong	0.47	100
yanjiamaoyuanzao	0.60	26	bx3b5	0.47	101
daguosuanpan	0.59	27	bayuezha	0.47	102
hongdayihao	0.59	28	zunyitianzao	0.47	103
jinai 2	0.59	29	zhongzao 3	0.47	104

Table 5. *Cont.*

Variety	Score	Ranking	Variety	Score	Ranking
tuanzao	0.59	30	lingzao	0.46	105
shandonglizao	0.59	31	gagazao	0.46	106
lantiandazao	0.59	32	dongzao	0.46	107
manmanzao	0.59	33	xinzhenghong 2	0.46	108
misu 1	0.58	34	bd2b2	0.46	109
jinlingyuanzao	0.58	35	bopicui	0.46	110
heigeda	0.58	36	qiumeizao	0.46	111
xupujianzao	0.58	37	pingguozao	0.46	112
huizaobianzhong 1	0.58	38	changjixin	0.45	113
hetaowen	0.57	39	jinsixin 3	0.45	114
huanghuadongzao 2	0.57	40	daliyuanzao	0.44	115
lejin 2	0.56	41	huizao	0.44	116
xupujidanzao	0.56	42	bx5n6	0.44	117
wubaodazao	0.56	43	bx6b6	0.43	118
zhongyangmuzao	0.56	44	mopanzao	0.43	119
hupingzao	0.56	45	meimizao	0.43	120
popozao	0.56	46	lejin 3	0.43	121
zanhuangdazao	0.56	47	fucuimi	0.43	122
shanghaibaipu	0.56	48	jinsimi	0.43	123
sanbianhong	0.55	49	fengmiguan	0.43	124
yanchuantiaozao	0.55	50	shanxiliuhao	0.43	125
binlangzao	0.55	51	guangyangzao	0.43	126
shanxijidanzao	0.55	52	duanguochanghong	0.43	127
fuxiang	0.55	53	mx10b5	0.43	128
fushuai	0.54	54	Zhongningxiaoyuan zao	0.42	129
habazao	0.54	55	naitouzao	0.42	130
banzao	0.53	56	jinsixin 1	0.42	131
zaoqiangcuizao	0.53	57	descendants of popozao	0.42	132
jinchang 1	0.53	58	zhongzao 1	0.42	133
shidingzao	0.53	59	lejin 1	0.42	134
jiuyuehan	0.53	60	dnjd6b4	0.41	135
mayabai	0.53	61	jinsixin 2	0.41	136
gutouxiaozao	0.53	62	dalizhizao	0.41	137
kulinzao	0.53	63	langjiayuan	0.40	138
mohuzao	0.52	64	wenzao	0.40	139
linxianyazao	0.52	65	mx7b6	0.40	140
huluzao	0.52	66	linxianshuituanzao	0.40	141
jun 1	0.52	67	dasuanzao	0.39	142
zaocuiwang	0.51	68	lelingwuhexiaozao	0.38	143
descendants of fengmiguan	0.51	69	mamazao	0.38	144
shanxizhizao	0.51	70	bx4b2	0.37	145
lejin 4	0.51	71	jinsixiaozao	0.35	146
lintongchegulu	0.51	72	hengyangzhenzhuzao	0.33	147
yueguang	0.51	73	baodeyouzao	0.33	148
jinlingchangzao	0.50	74	jinsixin 4	0.32	149
Xinzhengxiaoyuan zao	0.50	75	suanzao	0.28	150

4. Discussion

Rich germplasm resources serve as the fundamental basis for novel cultivar selection and breeding programmes. Phenotypic variation provides valuable insights into the extent of genetic diversity within a species. Comprehensive characterisation of phenotypic traits and genetic variability in jujube germplasm is therefore essential to facilitate the optimal utilisation of these valuable genetic resources [16,17]. This study conducted a genetic diversity analysis on 150 varieties of jujube genetic materials. The coefficients of variation for the number of fruit-bearing spurs and petiole width were the highest, ranging from 1.1 to 6.67 (units) and 0.78 to 2.45 (mm), respectively. The two traits of flowers with smaller coefficients of variation were flower size and nectar disc size, indicating that the organs of flowers have become more stable in the long-term evolutionary process of genetic traits, and are less affected by the external environment, a result similar to that of Yang Lei et al. [18]. In their analysis of the diversity of phenotypic traits in 118 jujube varieties, they found

that the average coefficient of variation in phenotypic traits of flowers was small. With the exception of flower size, nectar disc size, and leaf length, all evaluated traits exhibited coefficients of variation exceeding 10%, demonstrating substantial phenotypic diversity within the germplasm [19]. The mean coefficient of variation for fruit quality traits was 8.35%. This finding is consistent with previous research by Chen et al. [20], who reported substantial phenotypic variation in jujube core germplasm resources. Their study identified fruit longitudinal diameter, fruit splitting index, kernel index, and fruit shape index as the principal contributors to phenotypic diversity in jujube core germplasm. It was found that jujube germplasm is highly diverse in traits such as nutrition, foliage, fruit size, fruit shape, fruit flavour, and seed, which can be used in breeding programmes [21].

The Shannon–Weaver diversity index (H′) represents a fundamental metric for assessing plant biodiversity, with widespread application in the evaluation of phenotypic trait variation [22]. From the genetic diversity index, the diversity index of descriptive traits in jujube germplasm ranged from 1.47 to 5.01, with the highest diversity indices of flower size and nectar disc size of 5.01 and the lowest diversity index of petiole width of 1.47. The diversity indices of fruit quality traits ranged from 4.92 to 5.01, with the highest diversity indices of soluble solids of 5.01 and the lowest diversity indices of single fruit weight of 4.92. A higher genetic diversity index indicates richer diversity [23]. The observed discrepancy with findings reported by Han et al. [24] may be attributed to differences in sample size and population characteristics between studies. Cluster analysis, an established statistical method for grouping samples based on trait similarity [25], effectively revealed distinct varietal classifications that reflect fundamental phenotypic relationships among the evaluated accessions. Cluster analysis outcomes varied depending on the selected trait datasets. When analysed based on fruit quality characteristics, the germplasm resources were classified into four distinct groups: Class I included only suanzao, which was characterised by smaller fruit appearance, higher acidity, and lower sugar content; Class II included 36 materials, and this group was characterised by larger fruit size, lower content of soluble solids, soluble sugars, and total phenolics; and Class III included 33 groups of materials, which were characterised by longer fruit size and higher total phenolics. Class IV is the largest group, including up to 70 materials, which is characterised by smaller fruits, higher soluble sugar content, soluble solids, vitamin C content, etc., and better performance in a number of indicators. Cluster analysis can show the connection between varieties with similar characteristics [26]. The selection of materials in this study included suanzao, which is a special material compared with other germplasms, and in the cluster analysis of fruit quality, suanzao became a separate category, which is characterised by small leaf blades, small fruits, abundant branch thorns, and high acidity and vitamin C content. Cluster analysis is a comprehensive examination and classification of qualitative and quantitative traits, with fewer subjective factors and more objective and scientific results [27].

The principal component analysis method transforms multiple indicator traits into a small number of comprehensive indicators that can cover more information by means of data dimensionality reduction [28]. Principal component analysis of fruit quality traits across all germplasm materials yielded six significant principal components collectively accounting for 86.87% of the total phenotypic variation. It indicates that it can represent most of the information of 150 jujube germplasm resources, and the evaluation indices were screened for subsequent comprehensive evaluation using factor analysis. Duan et al. [29] screened the evaluation indexes of the quality of fresh jujube fruits, which mainly include fruit colour, fruit flavour, water content ratio, fruit shape, vitamin C, and protein content in fruits and fruit size. Xue et al. [30] screened the main indices affecting the quality of jujube fruits as the quality of single fruit weight, the solid–acid ratio of the fruits and the sugar-acid ratio of the fruits, and the content of soluble solids and vitamin C in the

fruits, respectively. Cao Ge et al. [31] carried out principal component analysis on the fruit quality of 24 live progeny of "Fucuimi" jujube, and the main indicators affecting the fruit quality of jujube were longitudinal and transversal longitude, single fruit weight, water content ratio, soluble sugar content, and soluble solids. The results of the analysis in this study were basically consistent with the above screening results of fruit quality evaluation indexes. The top 20 germplasms were selected according to the ranking to provide a basis for subsequent jujube variety selection. Among them, those suitable for drying include the following: Sanlengzao (ripening in early September), Zan 2 (medium maturity varieties, larger leaves), Damuzao (late maturity varieties), and Hamazao (late maturity varieties). Those suitable for fresh consumption include the following: Jing 39 (fruit texture is more brittle, obvious cracking), Jinzao 1 (late maturity varieties, fruit texture is crisp), and MX5N3 (Jing 39 offspring) (large fruit type late maturity varieties, texture is crisp). Those suitable for both fresh consumption and drying include the following: Jinmanguo (late maturity varieties), Ningyanglingzao (fruit texture is loose and the fruit shape is neat), and Jinai 4 (earlier varieties). Those suitable for ornamental drying include the following: Linyilajiaozao (ripening in mid-September, fruit similar to the shape of chilli pepper) and longzao (late maturity, with a distinctive branch bending angle and a neat, productive fruit shape).

At present, phenotypic traits are still the most basic methods and approaches for germplasm resources research [32]. By studying the phenotypic diversity of species, one can gain a deep understanding of the variation structure, evolutionary origin, and patterns of germplasm resources [33]. This study systematically characterised phenotypic variation and genetic diversity in the jujube germplasm through a comprehensive analysis of both quantitative and qualitative traits. The findings provide a valuable foundation for the targeted selection and breeding of superior jujube cultivars. Future investigations should incorporate expanded germplasm collections integrated with molecular marker analyses to elucidate the genetic architecture of jujube diversity. Such integrated approaches will advance molecular breeding strategies and enhance cultivar development for improved jujube breeding and cultivation technology. Through these comprehensive research tools, jujube germplasm resources can be more effectively protected and utilised to promote the sustainable development of the jujube industry.

5. Conclusions

The mean value of the coefficient of variation for the 18 quantitative traits was 15.02%, and the mean value of the coefficient of variation for the fruit quality traits was 8.35%, indicating that the germplasm had rich phenotypic variation in morphological traits such as leaves, branches, and fruits. The Shannon–Wiener diversity index (H′) analysis showed a high phenotypic diversity of jujube germplasm resources. Factor analysis extracted six principal components, and a comprehensive evaluation screened out the germplasms with excellent comprehensive traits, such as sanlengzao, linyilajiaozao, zan 2, jinmangguo, jing 39, jinzao 1, damuzao, hamazao, ningyanglingzao, longzao, jinai 1, jinai 4, jun 2, xuanchengyuanzao, dabailing, mx5n3, jingudazao, linxianheyizao, shandongpingguo, and zan 1, providing an important opportunity for the genetic improvement and variety selection of jujube trees. Genetic improvement and variety selection provide an important resource base and scientific basis.

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Abbreviations

The following abbreviations are used in this manuscript:

Min	Minimum
Max	Maximum
Mean	Arithmetic mean
SD	Standard deviation
CV	Coefficient of variation

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