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Morphological, Yield and Quality Assessment of Grape Germplasm (*Vitis vinifera* L.) Grown under Pune Condition

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ABSTRACT

The present study was conducted during growing season October, 2024 to March, 2025 at ICAR-National Research Centre for Grapes, Pune, highlighting the considerable diversity for morphological, yield and quality characters among different colour-seeded grape germplasms grown. Most accessions exhibited medium to late bud brust; a trait more strongly modulated by post-pruning temperature than genetics. Shoot tips were predominantly half-open and young leaves exhibited yellow bronzed spotting, while mature leaves were large and wedge-shaped with five lobes, open petiole sinuses, variable prostrate hair densities and an absence of erect hairs. Bunch morphology was characterized by medium compactness with conical to cylindrical shapes, uniform black-skinned berries and flavour profiles ranging from neutral to muscat and foxy. Quantitative analyses revealed significant variation such as average bunch weight ranged from 100.5 g (Madhu Angoor) to 473.0 g (Katta), fifty-berry weight from 86.0 g (E-5-12) to 295.0 g (Ribier), and yield vine^{-1} from 1.41 kg (Madhu Angoor) to 21.52 kg (Gulabi). Total soluble solids spanned 11.5°Brix to 19.0°Brix and acidity ranged from 0.40% to 0.70%. Correlation analysis highlighted positive associations between bunch weight, length (r=0.631) and negative relationships with TSS (r=–0.458) and compactness (r=–0.583). Principal component analysis extracted twelve components, with the first three explaining 73.58% of total variance PC1 captured maturity and size dimensions, PC2 emphasized berry size and compactness and PC3 reflected productivity. These findings underscored the value of morphological and pomological markers for germplasm discrimination and inform targeted parent selection in grape breeding programs aimed at enhancing yield and fruit quality.

KEYWORDS: Diversity, grapes, morphology, quality, yield

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1. INTRODUCTION

Grape (*Vitis vinifera* L.) is among the most widely grown fruit crops globally and is estimated to comprise between 6,000 and 10,000 cultivars around the world (Myles et al., 2015; Laucou et al., 2018). A great majority of *V. vinifera* L. subsp. vinifera cultivars widely cultivated for fruit, juice and wine, derived from wild forms V. vinifera L. subsp. sylvestris (Gmelin) Hegi (Rossetto et al., 2002; Sefc et al., 2003; Crespan, 2004, Khadivi-Khub et al., 2014). Grapevine cultivation and domestication took place between the seventh and fourth millennia BC in a geographical area between the Black Sea and Iran (McGovern and Rudolph, 1996; Zohary and Hopf, 2000). Viticulture has been a part of the history and tradition. Cultivated grapes are believed to have been introduced to India around 1300 AD by Muslim invaders from Iran and Afghanistan (Thapar, 1960). The world vineyard surface area is estimated to be 7.2 mha, with the production of 27.9 million mt. Major grape producing countries are China, Italy, France, Spain, USA, Turkey and India (OIV, 2024). At present, Maharashtra, Karnataka and Tamil Nadu are the major grape growing states in India. According to II advance estimates of 2023, an area of 175 th ha was covered under grapevine cultivation and production was 3896 in the country (Anonymous, 2024).

Landraces, improved varieties, hybrids and wild relatives comprises the wide range of grape variety that must be conserved to provide rich genetic variability for various breeding purposes (Dolkar et al., 2018). Researchers and scientists worldwide have shown increased interest in grape genetic resources now that their importance is recognized. Germplasm plays major role in understanding gene functions, creating enhanced varieties and preserving species (Ates et al., 2011; Khadivi et al., 2019). Consequently, evaluating grape diversity is a vital step in the characterization and conservation of grape germplasm, which is essential for sustaining and enhancing crop productivity.

Historically, the identification of grape varieties has been based on examining the morphological features of both the plant's growth and its reproductive organs. Ampelography studies are beneficial for identifying grape cultivars (Fatahi et al., 2004). In recent years, there has been a significant increase in genomic resources available to the grapevine research community, driven by a renewed focus on grapevine (*Vitis vinifera* L.) germplasm resources and the analysis of genetic diversity in grapes. In the past, grape quality was primarily judged by physical characteristics such as berry and bunch size, shape and weight. However, as scientific research has increasingly highlighted the nutritional and health benefits of grapes, consumer preferences are shifting toward varieties with enhanced nutritional value (Razvan et al., 2017). It is extremely important resource, not only because of its fruit, but also because of the presence of secondary metabolites in its cellular structure. Resveratrol is a secondary metabolite that acts as an antioxidant that protects the body from high risks (Arslan et al., 2023). The medicinal benefits are extensively recognized in traditional Indian medicine, including properties such as antioxidant, antidiabetic, cardioprotective, neuroprotective, anticancer, immune-boosting, antiatherogenic, anti-obesity, anti-aging, antimicrobial and fever-reducing effects (Somkuwar et al., 2023).

In recent years, efforts to safeguard existing grapevine germplasm diversity have become important across all grape-producing nations. The long-term preservation and effective utilization of grapevine genetic resources depends upon proper documentation, evaluation and management of germplasm. These steps are essential to ensure the survival of genetic material and its continued use in breeding programs, scientific research and grape production. Considering these, the aim of this study was to evaluate the important morphological, yield and quality characteristics of the accessions and to introduce these valuable accessions from heritage germplasm in India to breeders, researchers and grape producers who care about the quality characteristics of new germplasms for production in more vineyards.

2. MATERIALS AND METHODS

2.1. Experimental site

The study was carried out during October, 2024 to March, 2025 at ICAR-National Research Centre for Grapes, Pune. The age of the vineyard was seven years old with good health and regular crop. The vines were trained to a Y trellis system with single cordons trained in the horizontal direction while shoots were placed in a vertical position. The design of the experiment was RBD and each plant represented a single treatment replicated three times. The germplasms included in the study were as follows (Table 1).

2.2. Morphological characterization

Ampelographic characterization of each germplasm was performed according to the descriptor list for Vitis species (Anonymous, 2007) from November, 2024 to March, 2025. Twenty-eight morphological characters were used to assess the range of variation among the cultivars. The morphological characteristics examined were leaf, berry and bunch type. These characteristics were recorded based on descriptors issued by the International Organization of Vine and Wine (OIV). Each characteristic was given an OIV code and a numerical value that reflects its measurement. Berry and bunch features were determined at full veraison when berries had completely developed colour. For assessment of bunch morphology, ten bunches germplasms^{-1} were used. For berry morphology, ten berries

Table 1: Information about the different colour seeded grape germplasms

Sl. No.	Germplasm	Parents	Origin	Breeder	End Use
1.	Katta	Not Available	Iran	Not Available	Table or Juice grapes
2.	E-8-5	A cross of Anab-E-Shahi×Convent Large Black	India	Not Available	Table Grape
3.	Italian Eliquana	Not Available	Europe	Not Available	Table grape with good keeping quality
4.	Madhu Angoor	A clonal selection, probably from Carolina Black Rose	ANGRAU, Hyderabad, A.P. India (1997)	Not Available	Table or raisin
5.	Carolina Black Rose	A cross of Aurelia × Black Rose	USA	Not Available	Table
6.	Gulabi	Not Available	Not Available	Not Available	Wine or table grape
7.	E-5-12 (AES×BC)	Anab- E-Shahi×Black Champa	Bengaluru	Not Available	Wine or juice
8.	Ribier	Not Available	France	Not Available	Wine or table grape
9.	Arka Shyam	Cross of Bangalore Blue×Black Champa	IIHR B'luru	Dr. S.S. Negi	Juice or wine grape
10.	Concard	Not Available	USA	Not Available	Popular juice or wine grape
11.	Gulabi×Bangalore purple	Cross of Gulabi×Bangalore Purple	Not Available	Not Available	Excellent for juice
12.	Bangalore Purple	Not Available	Bangalore	Not Available	Juice
13.	E-8-24 (AES×Convent Large Black)	Anab-E-Sahebi×Convent Large Black	IIHR, Bangalore	Not Available	Wine or Juice
14.	Black Champa	Not Available	Unknown origin form India	Not Available	Juice or Wine
15.	Convent Large Black	Not Available	France	Not Available	Table or wine

from each of the ten chosen bunches were selected at random (Anonymous, 2009).

2.3. Yield and quality characterization

Quantitative characters were recorded using laboratory instruments like a digital vernier caliper, weighing balance and digital hand refractometer. Bunch weight was recorded using an electronic balance. Bunch and berry size (length and width) were recorded using digital vernier caliper, number of berries bunch^{-1} were manually counted. Fruit juice was utilized to the analysis of total soluble solids (TSS) and titratable acidity (TA). TSS was measured using a digital hand refractometer and was given in °Brix. Titratable acidity was determined by titration using a N/1 0 NaOH titration medium and index of phenolphthalein.

2.4. Statistical analysis

Analysis of variance (ANOVA) was conducted for yield and quality traits using one-way ANOVA in SAS software (SAS Institute). For each parameter, the mean and standard deviation (SD) were calculated. Additionally, the coefficient of variation (CV%) was used to assess the extent of variability. To explore the relationships among cultivars, principal component analysis (PCA) was carried out using SPSS Statistics software.

3. RESULTS AND DISCUSSION

3.1. Young shoot characters

Table 2 present the data on morphological characterization of colour seeded grapes germplasms. The characterization of fifteen grape accessions based on 27 morphological and pomological traits revealed significant variation across several descriptors. Most of the accessions exhibited a medium (9) to late (6) timing for bud burst. Bud break was a varietal character as it marked the beginning of seasonal growth and was strongly influenced by temperature. The data on the growth parameter clearly indicated that prevailing temperature after pruning affects the time required for bud break in the same variety and the influence of temperature was more than that of variety (Somkuwar et al., 2024a). The shoot tip was primarily half open (8), with fewer accessions showing fully open (4) or closed (3). Young leaf coloration varied with a majority displaying yellow with bronze spots (8), followed by copper yellow (3). Full bloom occurred mostly late (10), with a few accessions flowering at medium (3) stages. Inflorescence shoot^{-1} ranged mainly between one to less than two (8), while some had two to less than three (4) or less than one (3). Most vines exhibited an erect growth habit (14). Ates et al. (2011) also used this trait to classify ten grape cultivars as either horizontal or erect types.

3.2. Young leaf characters

The width of mature leaves was generally large (9) or very large (6) and blade shapes varied with wedge (7), cordate (4), pentagonal (3) and kidney (1) forms observed. Lobing of mature leaves ranged from one (2) to eight (2) with five lobes being most common (5). Abiri et al., (2020) who reported that most accessions had five lobes in 23 out of 55 cultivars. Similarly, Vafaee et al., (2017) found 30 out of 31 cultivars exhibited five lobes. Anthocyanin coloration on the lower main vein was absent in 5 accessions, while others showed pigmentation at the first (3) and second bifurcation (2) and at the point (5). Most leaves had wedge-shaped teeth (14), and the petiole sinus was predominantly open (11), though very wide (3) and closed (1) forms were also present. Prostrate hairs between lower veins varied with medium (5), high (4), very high (3), very low (2) and absent (2) densities

Table 2: Frequency distribution of different morphological characters of colour seeded grapes germplasms

Sl. No.	Characters	Frequency (No. of germplasms)					
1.	Time of bud brust	Medium (9)	Late (6)				
2.	Young shoot: opening of shoot tip	Half open (8)	Fully open (4)	Closed (3)			
3.	Young leaf: Colour of upper side of blade	Yellow with bronze spot (8)	Yellow (2)	Copper yellow (3)	Green with bronze spots (2)		
4.	Time of full bloom	Medium (3)	Late (10)	Very late (2)			
5.	Inflorescence: average number of inflorescences shoot^{-1}	Two to less than three (4)	One to less than two (8)	Less than one (3)			
6.	Shoot: growth habit	Erect (14)	Horizontal (1)				
7.	Mature leaf: width of blade	Large (9)	Very large (6)				
8.	Mature leaf: Shape of blade	Wedge (7)	Pentagonal (3)	Cordate (4)	Kidney (1)		
9.	Mature leaf: Number of lobes	One (2)	Three (4)	Five (5)	Six (1)	Sevan (1)	Eight (2)
10.	Mature leaf: Anthocyanin coloration of main vein on lower side of blade	Absent (5)	1st bifergation(3)	2nd bifergation (2)	Point (5)		
11.	Mature leaf: Shape of teeth	Convex (1)	Wedge (14)				
12.	Mature leaf: Degree of opening/overlapping of petiole sinus	Open (11)	Very wide open (3)	Closed (1)			
13.	Mature leaf: Prostrate hairs between veins on lower side of blade	Absent (2)	High (4)	Medium (5)	Very high (3)	Very low (2)	
14.	Mature leaf: erect hairs between veins on lower side of blade	Absent (15)					
15.	Mature leaf: Ratio of length of petiole compared to mid vein	Short (12)	Equal (3)				

Table 2: Continue...

Sl. No.	Characters	Frequency (No. of germplasms)				
16.	Physiological Maturity of berry (DAP)	Early (5)	Medium (3)	Late (7)		
17.	Time of veraison	Late(15)				
18.	Bunch: Berry density/ compactness in table grapes	Medium (10)	Compact (4)	Loose (1)		
19.	Bunch: Shape/type	Conical (6)	Cylindrical (5)	Winged cylindrical (1)	Winged conical (1)	
20.	Bunch: Uniformity of berry size	Uniform (15)				
21.	Berry shape	Short elliptical (4)	Long elliptical (2)	Round (7)	Oblate (1)	Conical (1)
22.	Berry: skin colour after removal of bloom	Black (15)				
23.	Berry: anthocyanin coloration of mesocarp	Absent (15)				
24.	Berry: flavour	Neutral (7)	Muscat (4)	Foxy (1)	Other (3)	
25.	Berry: length of pedicel	Short (10)	Very short (4)	Medium (1)		
26.	Berry: attachment with pedicel	Loose (3)	Firm (12)			
27.	Berry: Formation of seeds	Seeded (15)				

recorded. Erect hairs were absent in all the accessions studied (15). The petiole-to-mid-vein length ratio was mostly short (12). The leaf is the main part of the grapevine shoot. Ortiz et al. (2004) reported that mature leaf characters provide discriminative data for the identification and separation of genotypes. The variables density of erect and prostrate hairs on young and mature leaves was the most prominent factor in our study which differentiated the genotypes based on dissimilarity. Similar results were reported by (Ates et al., 2011) that the density of prostrate hair on young leaves played a significant role in the identification of grapevine genotypes. These findings were also similar to Somkuwar et al. (2024).

3.3. Bunch and berry characters

Berry maturity (DAP) ranged from early (5) to medium (3) and late (7), while veraison occurred late in all cases (15). Berry density in table grapes was mostly medium (10) with few compact (4) and one loose. Bunch shapes included conical (6), cylindrical (5), winged cylindrical (1) and winged conical (1). All accessions showed uniform berry size (15). Berry shapes varied round (7), short elliptical (4), long elliptical (2), oblate (1) and conical (1). All berries had black skin after bloom removal (15) and absent anthocyanin coloration in the mesocarp (15). Flavors included neutral (7), muscat (4), foxy (1) and other (3). Pedicel length was mainly short (10), very short (4), medium (1), with attachment either firm (12) or loose (3). All the grape accessions produced seeded berries (15). Grape bunch and berry characters have their significant role in quality assessment (Dilli et al., 2014). In grape improvement program, morphological marker helped in the selection of trait-specific parents. Differences in morphological characters such as, presence of seed in berry, berry flavour, berry shape, etc could help to select the progeny (Somkuwar et al., 2023). As also earlier reported by Dicenta and Garcia (1992), a close relationship between traits could also facilitate since strong selection for a desirable trait could favor the presence of another desirable trait from available germplasm.

3.4. Yield and quality characteristics

Table 3 represent quantitative analysis of 15 grape germplasm emphasized significant variation within traits relevant to yield and fruit quality. Among the accessions, Katta showed the maximum average bunch weight (473.00 g), which was followed by E8/5 (347.17 g) and Italian Eliquana (300.17 g). On the other hand, Madhu Angoor and Concard possessed minimum bunch weights (100.50 g and 108.67 g, respectively). The variation in bunch weight across different germplasm could be attributed to the inherent genetic characteristics of each germplasm, the number of berries per bunch, differences in the number of canes, berry size, and the size of the vine canopy. Germplasms with larger canopy sizes produced higher bunch weights. Similar findings have also been previously reported by Somkuwar et al., (2024b). The maximum 50-berry weight was recorded in Ribier (295.00

Table 3: Qualitative characters of different colour Seeded grape germplasms

Sl. No.	Germplasm	Average bunch weight (g)	50 Berry weight (g)	Number of berries $bunch^{-1}$	Berry diameter (mm)	Berry length (mm)	TSS (°B)
1.	Katta	473.0	159.00	68.00	15.1	20.7	14
2.	E-8-5	347.20	226.00	60.00	16.72	23.27	16.00
3.	Italian Eliquana	300.17	180.00	75.67	18.75	23.78	15.00
4.	Madhu Angoor	100.50	188.50	135.00	19.54	21.10	14.00
5.	Carolina Black Rose	282.83	161.00	105.00	16.70	19.77	15.50
6.	Gulabi	256.00	174.50	100.33	14.17	15.08	16.00
7.	E-5-12	275.83	86.00	60.67	14.20	14.30	17.00
8.	Ribier	308.67	295.00	80.33	18.50	21.30	16.00
9.	Arka Shyam	146.00	97.00	70.33	14.12	15.71	17.00
10.	Concard	108.67	148.00	70.30	14.60	16.48	16.00
11.	Gulabi x B'lore purple	176.00	221.50	85.67	13.30	17.80	19.00
12.	B'lore Purple	338.00	267.00	105.00	18.58	20.58	11.50
13.	E-8-24 (AES×Convent Large Black)	181.83	207.50	60.67	20.86	23.00	17.00
14.	Black Champa	128.50	217.50	35.33	17.65	21.32	18.50
15.	Convent Large Black	280.50	165.00	63.00	18.33	18.90	17.00
	SEm±	3.69	2.07	1.09	0.14	0.19	0.14
	CD (p=0.05)	10.69	6.00	3.16	0.41	0.56	0.41

Table 3: Continue...

Sl. No.	Germplasm	Acidity (%)	Bunch length (cm)	Bunch compactness	Yield $vine^{-1}$ (kg)	Number of bunches	Days to harvest (days)
1.	Katta	0.70	23.3	1.79	6.16	13.00	131
2.	E-8-5	0.53	15.33	2.92	6.95	20.00	124.00
3.	Italian Eliquana	0.53	13.17	4.28	8.11	27.00	126.00
4.	Madhu Angoor	0.58	18.33	4.85	1.41	14.00	131.00
5.	Carolina Black Rose	0.53	15.00	4.77	7.93	28.00	125.00
6.	Gulabi	0.56	18.50	3.67	21.52	84.00	113.00
7.	E-5-12	0.51	17.27	2.66	13.53	49.00	113.00
8.	Ribier	0.53	15.37	3.88	14.22	46.00	115.00
9.	Arka Shyam	0.40	12.50	4.31	6.43	44.00	114.00
10.	Concard	0.48	7.83	6.06	5.12	47.00	116.00
11.	Gulabi x B'lore purple	0.48	10.67	5.74	6.70	38.00	110.00
12.	B'lore Purple	0.43	13.50	4.96	10.84	32.00	132.00
13.	E-8-24 (AES×Convent Large Black)	0.51	10.33	4.73	6.01	33.00	114.00
14.	Black Champa	0.49	10.17	2.83	2.96	23.00	110.00
15.	Convent Large Black	0.55	13.17	3.53	15.16	54.00	121.00
	SEm±	0.00	0.12	0.04	0.24	0.43	0.94
	CD (p=0.05)	0.01	0.35	0.11	0.70	1.26	2.73

g), followed by Bangalore Purple (267.00 g), whereas the minimum was in E5/12 (86.00 g). The variation in the weight of 50 berries might be due to the differences in their size. The maximum number of berries bunch^{-1} was recorded in Madhu Angoor (135.00), while Black Champa showed the minimum (35.33). The number of berries per bunch is influenced by the environmental conditions present during flowering and fruit set. Berry diameter varied between 13.30 mm (Gulabi×Bangalore Purple) to 20.86 mm (E-8-24), while berry length was maximum in Italian Eliquana (23.78 mm) and minimum in E5/12 (14.30 mm). Variations in berry size might be attributed to the different shapes of the berries. These results are in confirmation with the results reported by Petrie et al. (2000) and Somkuwar and Ramteke (2007). TSS ranged from 11.5°B in Bangalore Purple to 19.0°B in Gulabi×Bangalore Purple, showing variation in sweetness. The difference in the total soluble solids might be due to different period of maturity of different germplasm. Early-ripening grape varieties had lower TSS levels compared to those that ripen in mid-season or later (Kose 2014). Acidity varied narrowly from 0.40% (Arka Shyam) to 0.70% (Italia). Bunch length varied from 7.83 cm (Concard) to 23.33 cm (Italia) while bunch compactness was highest in Gulabi×Bangalore Purple (5.74). This might be due to varietal character or due to the operations performed during bunch development period. Similar findings were reported by Gargin et al. (2011). Vafaee et al. (2017) reported that bunch density was very loose (berries in the grouped formation and many visible pedicels) in most of the cultivars. Bunch density was important for table grapes as very dense bunches were often damaged during packaging and transporting. Highest yield vine^{-1} was recorded in Gulabi (21.52 kg) which was closely followed by Convent Large Black (15.16 kg) and Ribier (14.22 kg), whereas

Table 4: Correlation between different qualitative parameters in studied colour seeded grape germplasms

	Average bunch weight (g)	50 Berry weight (g)	No. of berries bunch^{-1}	Berry dia-meter (mm)	Berry length (mm)	TSS (°B)	Acidity (%)	Bunch length (cm)	Bunch com-pactness	Yield vine^{-1} (Kg)	No. of bunches	Days to harvest (days)
Average bunch weight (g)	1											
50 Berry weight (g)	0.162	1										
No of berries bunch^{-1}	-0.064	0.145	1									
Berry diameter (mm)	-0.006	0.508	0.108	1								
Berry length (mm)	0.250	0.620	-0.054	0.778	1							
TSS (°B)	-0.458	-0.205	-0.572	-0.326	-0.269	1						
Acidity (%)	0.518	-0.024	0.096	0.080	0.246	-0.221	1					
Bunch length (cm)	0.631	-0.132	0.339	-0.113	-0.030	-0.452	0.746	1				
Bunch compactness	-0.583	0.155	0.468	0.062	-0.084	-0.024	-0.536	-0.627	1			
Yield vine^{-1} (Kg)	0.386	0.009	0.065	-0.198	-0.420	-0.021	0.057	0.272	-0.213	1		
Number of bunches	-0.127	-0.196	0.005	-0.388	-0.694	0.274	-0.232	-0.100	0.115	0.828	1	
Days to harvest (days)	0.498	0.130	0.501	0.383	0.463	-0.871	0.412	0.492	-0.077	-0.204	-0.554	1

the minimum was recorded in Madhu Angoor (1.41 kg). Number of bunches vine^{-1} was maximum in Gulabi (84.00) and minimum in Italia (13.00). Maturity period varied from 110 days in Gulabi×Bangalore Purple and Black Champa to 132 days in Bangalore Purple indicating large variation in harvesting durations. The maturity, ripening, and harvesting time of grapes were influenced by the cultivar, geographical location, and prevailing agro-climatic conditions.

3.5. Correlation between yield and quality traits

Correlation between yield and quality parameters was presented in Table 4. Average bunch weight showed a strong positive correlation with bunch length (0.631) and acidity (0.518), and a moderate positive correlation with days to harvest (0.498) and yield vine^{-1} (0.386). It had a negative correlation with TSS (Total Soluble Solids) (-0.458) and bunch compactness (-0.583), indicating that as these traits increases, the average bunch weight tends to decrease. 50 Berry weight was positively correlated with berry length (0.620) and berry diameter (0.508), suggesting that larger berries contributed to heavier weights. It has weaker or negative correlations with other traits. Berry length and berry diameter were highly correlated (0.778), which was expected as longer berries tend to be wider. These two were also positively correlated with 50 berry weight but negatively with TSS, indicating larger berries might have lower sugar concentration. TSS (°Brix) has a notable negative correlation with many traits, especially days to harvest (-0.871), number of berries bunch^{-1} (-0.572), and average bunch weight (-0.458). Yield vine^{-1} was most strongly correlated with the number of bunches (0.828), implying that yield was more influenced by how many bunches were produced rather than the size of each bunch. It also showed a moderate positive correlation with average bunch weight (0.386). The correlation coefficient provided insights into the traits that were most important for assessing genotypes (Norman et al., 2011). The results of this investigation aligned with the findings of Somkuwar et al. (2024a) and Khadivi Khub et al. (2014).

Table 5: Eigenvalues and proportion of total variability and eigenvectors of twelve principal

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
Average bunch weight (g)	-0.314	-0.323	-0.11	0.224	-0.417	-0.261	0.314	-0.341	0.348	-0.128	0.061	0.369
50 Berry weight (g)	-0.18	0.253	0.031	0.569	0.145	-0.573	-0.252	0.308	-0.098	-0.209	0.133	-0.012
No. of berries bunch	-0.166	0.024	0.623	-0.119	0.356	-0.122	-0.183	-0.376	-0.079	0.003	-0.31	0.388
Berry diameter (mm)	-0.261	0.325	-0.038	0.321	0.19	0.669	-0.084	-0.085	0.315	-0.311	0.129	0.11
Berry length (mm)	-0.341	0.321	-0.243	0.222	0.068	0.013	0.164	-0.283	-0.217	0.709	-0.071	-0.07
TSS (°B)	0.373	0.023	-0.376	0.024	0.384	-0.14	0.101	-0.562	-0.257	-0.298	0.262	0.036
Acidity (%)	-0.308	-0.274	-0.169	-0.098	0.592	-0.028	0.52	0.358	0.016	-0.096	-0.181	0.026
Bunch length (cm)	-0.304	-0.414	0.042	-0.136	0.258	-0.059	-0.386	-0.147	0.262	0.201	0.499	-0.343
Bunch compactness	0.162	0.361	0.461	-0.038	0.044	-0.169	0.533	-0.084	0.342	0.023	0.268	-0.345
Yield per vine (Kg)	0.09	-0.402	0.209	0.522	-0.026	0.164	0.071	-0.203	-0.151	-0.098	-0.366	-0.523
Number of bunches	0.317	-0.287	0.259	0.354	0.089	0.214	0.148	0.213	-0.181	0.328	0.436	0.417
Days to harvest (days)	-0.442	0.018	0.21	-0.179	-0.252	0.126	0.176	-0.015	-0.64	-0.289	0.339	-0.1
Total	4.009	2.907	1.913	1.425	0.67	0.521	0.291	0.151	0.054	0.048	0.008	0.002
% of variance	33.412	24.224	15.943	11.873	5.586	4.343	2.424	1.256	0.453	0.396	0.07	0.02
Cumulative %	33.412	57.636	73.58	85.453	91.039	95.381	97.805	99.061	99.514	99.91	99.98	100

3.6. Principal component analysis (PCA)

Table 5 showed Principal component analysis of different yield and quality parameters. The PCA extracted 12 principal components (PCs) from the data, with the first few components capturing most of the variance. PC1 alone explained 33.41% of the total variance, and when combined with PC2 and PC3, the cumulative variance reached 73.58%, indicating that these three components captured a significant portion of the dataset's variability. By PC4, the cumulative variance exceeded 85%, and by PC6, it covered over 95%, which means dimensionality could be reduced substantially with minimal loss of information. Looking at PC1, it has strong negative loadings for days to harvest (-0.442), TSS (0.373), and berry length (-0.341), suggesting that these variables contributed significantly to the first principal component and were inversely related to it. This component likely captured a maturity and size dimension. PC2 has high positive loadings from berry diameter (0.325), berry length (0.321), and bunch compactness (0.361), and a strong negative loading from yield vine^{-1} (-0.402). This indicated PC2 was influenced by berry size and structural compactness, possibly representing a morphological trait axis. PC3 was mainly defined by number of berries bunch^{-1} (0.623) and bunch compactness (0.461), representing a density and productivity-related component. Interestingly, PC4 highlighted 50 berry weight (0.569) and yield vine^{-1} (0.522) as major contributors, suggesting it might reflect yield quantity and berry mass. Further, components like PC5 (with high loading for acidity at 0.592) and PC6 (with a dominant contribution from berry diameter at 0.669) explained smaller amounts of variance but were useful for capturing more specific traits. Overall, this PCA revealed that the variability in the dataset was largely driven by a few key characteristics related to berry size, bunch structure, maturity time, and yield that reduced number of components could effectively describe most of the data's structure. This could be extremely useful in varietal selection, trait prioritization, or further multivariate analyses in viticulture research. These characters were also important in determining the breeding requirements for grape species (Vafaee et al., 2017).

4. CONCLUSION

The cultivated colour grape gene pool exhibited considerable genetic diversity. A broad range of variation was observed in both phenotypic and genotypic traits, reflecting their strong potential for use in breeding programs. The germplasms showed substantial diversity across most characteristics, particularly in berry-related traits.

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