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Genotypic variability and trait associations in Indian jujube under semiarid conditions

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Abstract

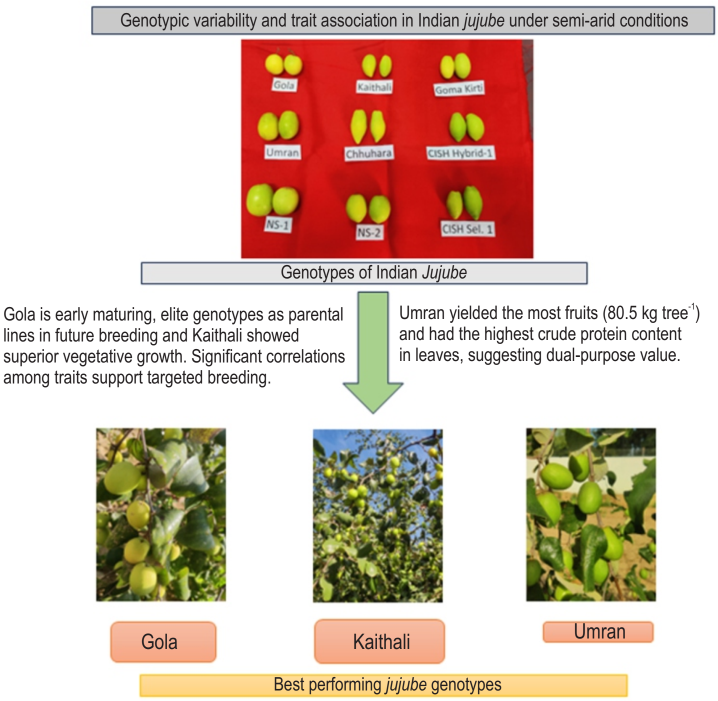
Aim: To characterize and quantify genetic variability of ber genotype via Principal Component Analysis and Correlation Analysis for crop improvement, which will be of immense important in formulating an effective breeding strategy for the genetic improvement of this crop.

Methodology: The experiment was conducted in a randomized block design with three replications. In the present study, nine ber genotypes were selected for evaluation during 2018--2023 (five years). The quantitative data on yield attributes and quality traits were recorded and subjected to PCA, and correlations among traits were subjected to analysis via R-Studio software.

Results: The findings of this comprehensive evaluation of Indian *jujube* genotypes are expected to have a significant impact on the identification of high-performing genotypes, such as 'Kaithali' for vegetative growth and fruit quality and 'Umran' for both yield and leaf protein content. This study supports the development of dual-purpose cultivars that can increase both fruit production and fodder availability.

Interpretation: A key novel finding is the identification of 'Umran' as a high-yielding genotype with superior leaf nutritive value, suggesting its suitability for horti-pastoral systems. The significant genotypic variability observed in terms of growth vigor, fruit morphometrics, and pulp characteristics provides a valuable genetic basis for selection and varietal improvement.

Key words: Genetic variability ber, Indian *jujube*, Principal Component Analysis



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Introduction

The Indian jujube (*Ziziphus mauritiana* Lamk.), king of arid zone fruits, is one of the most ancient fruits of the Indian subcontinent and has been found to grow in cultivated forms throughout the country (Pareek, 2001). The fruits are popular because of their sweet-sour taste and excellent nutritive value, pleasant flavour, high palatability and, most importantly, low cost, (Singh and Saxena, 2008). It is a rich source of vitamin 'B' complex and vitamin 'C'. However, ber is richer than apple in protein, phosphorus, calcium, carotene and vitamin C (Bishnoi and Kumar, 2025) and oranges in phosphorus, iron, vitamin C and carbohydrates and exceeds them in calorific value. This highly nutritive fruit crop is hardy, quick growing, precocious, high yielding and well adapted to moderate-alkaline to drier tracts of the country. Its cultivation requires minimal inputs and care but responds well to manuring, irrigation, training and pruning practices. The tree flowers in autumn and fruits mature during mid--late winter. The most common cultivars are the outcome of selection in various geographic areas. The lack of breakthrough is due to under-utilization of genetic variability of genetic variability for superior quality and high yield potential (Singh *et al.,* 2017).

Being a tropical and compelled cross-pollinated due to self-incompatibility, a lot of genetic diversity is expected in the species. Intra and inter specific genetic diversity of a plant species are important for tidy utilization in the breeding programme. Previous studies have focused primarily on individual traits of local germplasm particularly morphological and agronomic characteristics. Molecular diversity using markers such as SSRs and ISSRs have been widely employed because of their high polymorphism, reproducibility, and ability to detect variation at DNA level. These markers enable assessment of genetic similarity, population structure, and the identification of distinct genotypes (Kumar *et al*., 2022; Meena *et al*., 2023). However, despite these advances, many earlier investigations still lack a systematic information on the integration between fruit quality traits and multivariate statistical approaches such as principal component analysis in ber, integrated analysis combining PCA in correlation of commercially important traits remain scarce. The systematic efforts to link fruit trait variability with breeding strategies for quality improvement are largely missing. This existing diversity provides an opportunity for selecting suitable genotypes with desired characters of interest. Thus, evaluating the existing genetic variability is essential to identify the promising genotypes with a higher yield, improved nutritional properties. The present study was conducted to exploit genetic diversity among nine genotypes of *Z. mauritiana* (Lamk.) using multivariate tools to identify the most variables and prominent genotypes.

Materials and Methods

The present study was conducted at the Regional Research Station, Bawal, which is located at latitude 28.1°N, longitude 76.5°E, 266 m above mean sea level in the south-west zone of Haryana. The typical semiarid climate of this region is characterized by scorching, dry summers and extreme cold winters. In the present study, nine ber genotypes were selected for evaluation during 2018-2023 (five years). Growth parameters, like growth habit, plant height, plant spread (EW & NS) (m) and trunk girth, were observed in the month of August as per the ber descriptor of the ICAR (Krishna *et al.,* 2016). The morphological and physicochemical attributes of ber were recorded from fully mature and ripe fruits harvested from tagged branches from all four directions of the plant. The genotypes were categorized as early maturing (before 15th February), midseason (15th February to 15th March) and late maturing (after 15th March). The fully mature ber trees earmarked during the fruiting season, and mature fruits were randomly removed from the tagged trees to record data on fruit quality traits. These fruits were washed thoroughly with water to remove dirt and dust adhering to the fruit. Observations of several morphological parameters, *viz.,* mature fruit weight(g), mature fruit length (mm), mature fruit width (mm), stone weight (g), and the pulp to stone ratio, were recorded as per DUS guidelines (Mahajan *et al.,* 2002). A digital refractometer was used to directly quantify biochemical parameters, such as TSS content of fruit pulp (Brix: 0.0 to 53.0%), at 20°C.

The experiment was carried out in a randomized block design with three replications. The data presented are mean values parameters and were statistically analysed via the OPSTAT Online Agriculture Data Analysis Tool (CCS Haryana Agriculture University, Hisar) for ANOVA, and the mean values of different treatments were compared by critical differences in the mean CD (P value ≤ 0.05) between the treatments (Sheoran, 2004). Pearson's correlation was performed using the average of studied physico-chemical traits to highlight the associations between traits and distances between genotypes via R Studio (R Studio, PBC, Version 2022.07.1-554). Principal component analysis (PCA) was performed via R-Studio software. PCA, a tool for identifying patterns of physico-chemical variation in fruit characteristics within the ber accession collection, studying correlations among fruit quality measurements, and interpreting relationships between accessions, was performed via principal component analysis.

Results and Discussion

Assessment of ber genotypes is a prerequisite for collecting basic information before initiating any breeding programme for crop improvement. The assessment of ber genotypes revealed a wide range of phenological traits and fruit physical and biochemical characteristics. Significant differences among the cultivars were observed for the characters under study at p≤ 0.05. The data presented in Table 1 indicated that significantly maximum plant height (4.12 m) was observed in the Kaithali, which was at par with Umran (3.67 m) and Goma Kirthi (3.76 m). A significant maximum plant spread in the North-South (5.31 m) and East-West (5.43 m) was found in Kaithali genotype, which was at par with Umran, Chhuhara and Goma Kirthi., whereas Narendra Ber Selection 2 had the minimum plant height (1.84 m), plant spread NS (3.27 m), plant spread EW (3.18 m) and trunk girth 21.45 cm. The difference in growth parameters of

Table 1: Plant growth performance of different ber varieties during 2023

Cultivars	Plant height (m)	Plant spread N–S (m)	Plant spread E–W(m)	Trunk girth (cm)	Growth habit
Gola	2.29	3.81	3.81	30.57	Spreading
Umran	3.67	5.26	5.33	35.36	Semi-Spreading
Kaithali	4.12	5.31	5.43	39.62	Erect
Chhuhara	3.01	4.89	4.99	39.11	Semi-Spreading
Goma Kirthi	3.76	4.84	5.02	34.81	Semi-Spreading
Thar Sevika	2.59	4.29	3.96	31.61	Semi-Spreading
Thar Bhubhraj	2.12	3.71	3.42	24.64	Semi-Spreading
Narendra Ber Sel.1	3.35	4.62	4.54	37.48	Erect
Narendra Ber Sel. 2	1.84	3.27	3.18	21.45	Semi-Spreading
CD (P=0.05)	0.60	0.73	0.78	2.93	

Table 2: Variations in fruit characteristics among different ber genotypes

Cultivars	Pulp texture	Fruit crack	Fruit surface	Fruit shape	Fruit apex	Stone shape	Maturity group
Gola	Soft	Present	Plain	Oblate	Flat	Oval	Early
Umran	Hard	Absent	Ridge and Wart	Oval	Round	Oblong	Late
Kaithali	Soft	Absent	Plain	Ovate	Pointed	Club	Mid
Chhuhara	Medium	Absent	Plain	Falcate	Pointed	Falcate	Mid
Goma Kirthi	Medium	Absent	Plain	Ovate	Round	Oblong	Mid
Thar Sevika	Medium	Absent	Plain	Oval	Round	Oblong	Mid
Thar Bhubhraj	Medium	Absent	Plain	Falcate	Pointed	Falcate	Mid
Narendra Ber Sel. 1	Hard	Present	Plain	Oblate	Flat	Oval	Mid
Narendra Ber Sel. 2	Hard	Absent	Ridge and Wart	Ovate	Round	Spindle	Mid

different genotypes might be due to that inherent genetic makeup, climatic and edaphic factors (Dhandar and Shukla, 2004; Nagar *et al.,* 2017). The growth habits of different genotypes were observed as spread (Gola); semi-spreading (Umran, Chhuhara, Goma Kirthi, Thar Sevika, Thar Bhubhraj and Narendra Ber Selection 2); and erect (Kaithali and Narendra Ber Selection 1).

The genotypes also varied in terms of fruit physical parameters (Table 2). The pulp texture among different ber genotypes was soft (Gola, Kaithali), medium (Chhuhara, Goma Kirthi, Thar Sevika, Thar Bhubhraj) and hard textured (Umran, Narendra Ber Selection 1, Narendra Ber Selection 2). Fruits of the fruit cracking Gola genotype, Narendra Ber Selection 1, exhibited fruit cracking and splitting, whereas these events were absent in the remaining genotypes (Kaithali, Umran, Chhuhara, Goma Kirthi, Thar Sevika, Thar Bhubhraj). Fruit and stone morphological attributes; fruit surface – plain surface (Gola, Kaithali, Chhuhara, Goma Kirthi, Thar Sevika, Thar Bhubhraj, Narendra Ber Selection 1); ridge and wart surface (Umran, Narendra Ber Selection 2); Fruit shape – oblate (Gola, Narendra Ber Selection 1); oval (Umran, Thar Sevika); ovate (Kaithali, Goma Kirthi and Narendra Ber Selection 2); falcate (Chhuhara and Thar Bhubhraj); fruit apex – flat (Gola, Narendra Ber Selection 1), round (Umran, Goma, Thar Sevika, Narendra Ber Selection 2), pointed (Kaithli Chhuhara, Thar Bhubhraj); stone shape – oval (Gola, Narendra Ber Selection 1); oblong (Umran, Goma Kirthi, Thar Sevika); club (Kaithali); falcate (Chhuhara, Thar Bhubhraj); and Spindle (Narendra Ber Selection-2). Fruit and stone morphological features are useful for the identification and characterization of germplasms. This may be attributed due to genetic features of these genotypes which remain consistent under different growing conditions as reported by Meena *et al.* (2019) in ber. The genotypes had different maturity periods, such as early maturation (Gola), mid-season maturation (Kaithali, Chhuhara, Goma Kirthi, Thar Sevika, Thar Bhubhraj and Narendra Ber Selection 2), and late season maturation (Umran and Narendra Ber Selection 2). These results are in agreement with the previous findings in ber (Bal, 2001; Meena *et al.*, 2019) where considerable variation in fruit maturity among different ber genotypes were noted.

The physical and biochemical attributes of the fruit of different genotypes significantly varied (Table 3). Significantly, the maximum fruit weight (30.4 g) and pulp weight (28.3 g) were observed in Narendra Ber Selection 2 and minimum in Thar Bhubhraj. However, significant highest fruit length (49 mm) was observed in Chhuhara whereas fruit breadth was highest (37.0 mm) in Narendra Ber Selection 2. However,the minimum fruit length (34.5 mm) observed in the Gola and breadth (26.5 mm) was recorded in Chhuhara, which may be attributed to the fact that genetic potential of genotype-prevalent agroclimatic conditions significantly affects fruit attributes, *i.e.,* G × E

Table 3: Performance of ber varieties in terms of yield and yield characteristics from 2018--2023 (pooled data)

Cultivars	Fruit weight (g)	Fruit length (mm)	Fruit breadth (mm)	Pulp weight (g)	Stone weight (g)	TSS (°Brix)	Pulp: Stone ratio	Yield per plant (kg)	B:C ratio
Gola	18.3	34.5	32.0	17.1	1.23	18.46	13.9	45.2	2.5
Umran	24.6	46.0	35.0	23.1	1.54	16.72	15.0	80.5	4.5
Kaithali	21.9	45.0	32.0	20.8	1.05	16.49	19.8	63.5	3.6
Chhuhara	20.2	49.0	26.5	19.2	1.05	21.35	18.3	50.2	3.3
GomaKirthi	18.5	42.0	29.0	17.3	1.26	16.37	13.7	42.8	3.3
Thar Sevika	18.0	43.5	27.0	16.4	1.65	20.30	9.9	44.6	2.8
Thar Bhubhraj	16.8	42.0	27.0	15.6	1.21	19.09	12.9	46.9	2.6
Narendra Ber Sel1	28.8	36.0	35.0	26.2	2.55	18.10	10.3	60.6	2.1
Narendra Ber Sel2	30.4	42.0	37.0	28.3	2.17	17.62	13.0	40.4	1.9
CD (p=0.05)	1.3	1.10	1.02	1.00	0.26	2.32	1.4	4.8	

Table 4: Proximate composition and nutritive value (%) of leaves from different ber genotypes

Genotypes	Moisture (%)	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Nitrogen free extract (%)	Ash (%)
Gola	59.00	16.33	12.18	3.00	62.13	6.36
Umran	58.66	18.87	13.47	3.30	58.77	5.59
Kaithali	60.66	16.12	15.06	3.35	59.74	5.73
Chhuhara	60.00	17.36	16.25	3.67	57.13	5.59
GomaKirthi	61.66	16.73	13.36	3.50	59.63	6.78
Thar Sevika	62.33	16.75	14.00	3.12	59.24	7.26
Thar Bhubhraj	60.33	14.89	12.33	3.37	62.15	6.89
Narendra Ber Sel-1	57.66	16.16	13.81	3.37	60.13	6.53
Narendra Ber Sel-1	61.66	16.73	13.36	3.50	59.63	6.78
CD (p=0.05)	0.23	0.73	0.15	0.09	0.81	0.63

interactions (Nagar *et al.,* 2018). The stone weight among the test genotypes ranged between 1.05 and 2.55 g. The pulp to stone ratio was highest in Kaithali (19.8), followed by Chhuhara; however, it was lowest (9.9) in Thar Sevika. The difference in the physical parameters of fruits among ber genotypes may be attributed to the fact that high heterozygosity of genotypes and each genotype have unique fruit size at fruit maturity, due to their genetic makeup, leading to differential ovarian tissue development rates, which are further affected by agronomic practices, plant nutrition, and prevailing agro-climatic conditions (Singh *et al.,* 2019). The physical attributes of fruits are important criteria for selecting a new suitable genotype and selecting parentage(s) during hybridization programs.

The biochemical characteristics of TSS of various genotypes varied significantly among the evaluated ber genotypes (Table 3). A significant highest TSS was recorded in Chhuhara (21.35 °Brix), which was at par with Thar Sevika (20.30 °B) and Thar Bhubhraj (19.09 °B).These findings align with prior reports of Pareek *et al.* (2009) in ber. This effect might be due to the seasonal and climatic fluctuations within the region, moreover dry weather conditions tend to promote higher TSS contents in most cultivars (Singh and Misra, 2012). Similar results were reported earlier in ber (Ahmed *et al.,* 2003; Meena *et al.,* 2019; Rao and Subramanyam, 2010). Compared with other genotypes, the Umran genotype recorded the highest yield (80.5 kg tree^{-1}) whereas the Narendra Ber Selection 2 genotype presented the lowest yield (40.4 kg tree^{-1}) during the experimental period. Similar results were reported by Kumar *et al.* (2024) in ber that Umran had highest yield due to its genetic potential.

The proximate composition of ber leaves from nine genotypes revealed significant variation in their nutritional attributes (Table 4). Significantly the highest moisture content (62.33 %) and ash (7.26 %) were observed in Thar Sevika whereas crude protein (18.87 %) was found highest in Umran, which might be due to the influence of environmental and edaphic conditions that affect the moisture content and ash content in different genotypes as reported by Pathak *et al.* (2003), which influence the animal palatability and higher crude protein in Umran genotype used as supplement for protein powered roughage. Significant difference among the treatments was observed for crude fibre (16.25 %) and ether extract (3.67 %), in Chhuhara whereas the maximum nitrogen free extract (62.15 %) was in Thar Bhubraj, which was at par with Gola. It was obsereved that the genotypes Umran, Chhuhara and Thar Sevika had superior leaf nutritive profiles and suitability for use as dryland fodder. The result of the present study revealed significant

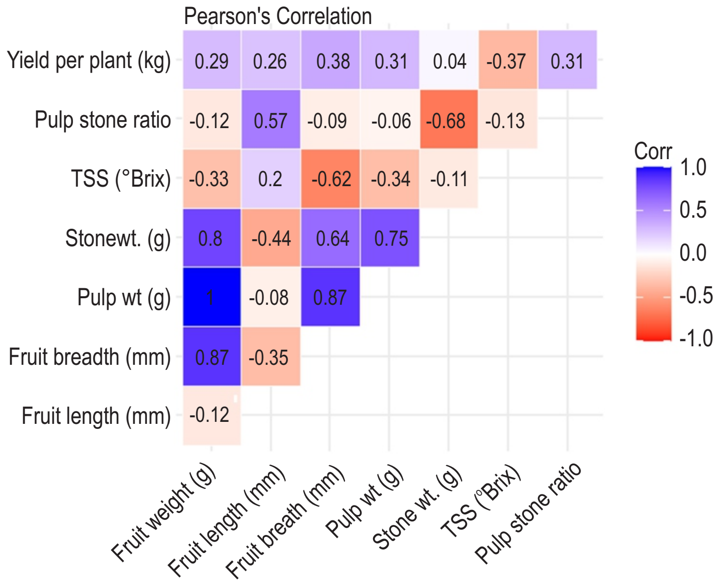

Fig.1: Pearson correlation coefficient analysis between yield and fruit traits. The positive correlation while moving towards the dark blue colour and a negative correlation when moving towards the dark red colour.

correlation among various fruit-related traits (Fig. 1) in different ber genotypes that can be exploited for varietal improvement and selection. Pulp weight was strongly and positively correlated with fruit weight (r = 1.00) and fruit breadth (r = 0.87). This suggests that genotypes with broader and heavier fruits tend to have a higher pulp content, which is desirable for fresh consumption and processing industries. Similar findings were reported by Awasthi and More (2009), who reported that pulp content was significantly associated with overall fruit size parameters in *Ziziphus mauritiana* (Lamk.). Stone weight was also positively correlated with fruit weight (r=0.80) and pulp weight (r=0.64), indicating that larger fruits may have larger stones, although the pulp-to-stone ratio can vary among genotypes. However, a high pulp stone ratio is preferred, and it had a moderate positive correlation with fruit length (r=0.57), but a negative correlation with TSS (r=-0.68), implying that sweeter fruits may not always have a favourable pulp-to-stone ratio. These findings are in line with the findings of Singh *et al.* (2012), who emphasized the trade-off between sweetness and pulp and yield in berfruits. The yield per plant was moderately and positively correlated with fruit weight (r = 0.29), fruit breadth (r = 0.38), and pulp weight (r = 0.31), suggesting that higher yield is generally associated with larger fruits. Kumar *et al.* (2024) also noticed a significant correlation between fruit physico-chemical traits in ber. However, TSS had a negative correlation with yield (r = -0.37), indicating a possible dilution effect, where high-yield genotypes may accumulate less sugar in fruits, as reported by Aulakh *et al.* (2005). TSS was positively correlated with fruit breadth (r = 0.20) and fruit length (r = 0.62), indicating that elongated fruits tend to be sweeter.The association between fruit attributes indicates their possibilities for simultaneous improvement in breeding programs and selecting desirable fruits (Karimi *et al.,* 2020). The principal component analysis (PCA) was estimated to determine the principal characters of total variability in *jujube* genotypes (Zareia *et al.,* 2019; Anjum *et al.,* 2018).

The scree plot (Fig. 2) illustrates the percentage of variance explained by each principal component (PC). The first principal component (PC1) accounts for the largest proportion of variance at 49.1%, followed by PC2 at 25.5% and PC3 at 12.9%. Together, the first three components explained 87.5% of the total variance, indicating that a majority of the data's structural variability can be effectively summarized in just three dimensions. Beyond PC3, the explained variance decreased sharply, with PC4 contributing 7.4%, PC5 contributing 4.2%, and subsequent components accounting for negligible variance (less than 1%). This suggests that higher-order PCs contain minimal unique information and are likely dominated by noise. On the basis of "elbow criterion", where the slope of the curve visibly flattens after a certain point, it is appropriate to retain the first three to four PCs for downstream analysis. This dimensionality reduction helps simplify the dataset without substantial loss of information, which is particularly beneficial for multivariate trait evaluation, genotype discrimination, and clustering. Similar results were obtained by Jolliffe and Cadima (2016) who reported that a few principal components often capture a large portion of variance in agro-morphological or biochemical traits.

Further, a biplot (Fig. 3) was constructed based on the PC1 and PC2, which effectively differentiate the ber genotypes on the basis of multiple fruit and yield-related traits. The first two principal components (Dim1 and Dim2) explain 74.6% of the total variation, with PC1 accounting for 49.1% and PC2 accounting for 25.5%. Dim1 is influenced primarily by traits such as fruit weight, pulp weight, fruit breadth, and stone weight, indicating that these

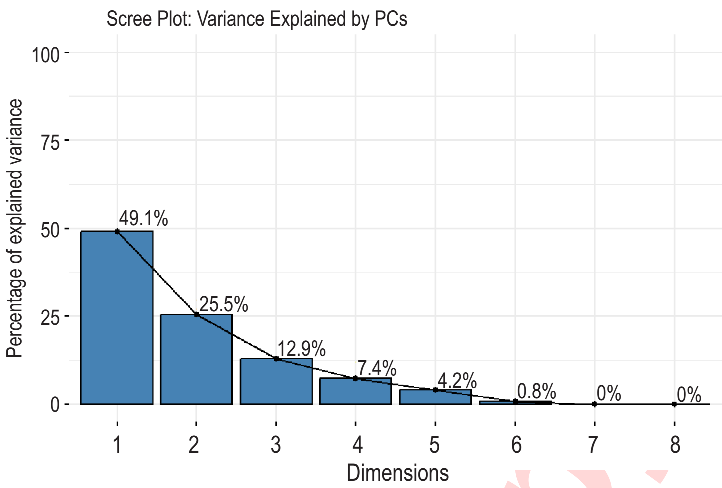

Fig. 2: Scree plot showing the principal component of ber.

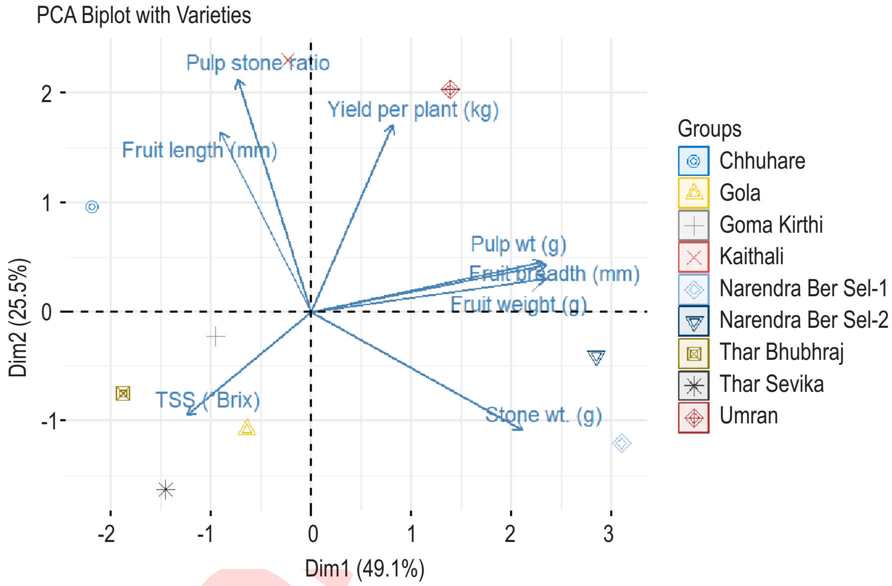

Fig. 3: PCA Biplot showing the characterss linked with genotypes with respect to PC1 and PC2.

parameters are major contributors to overall genotype variability. Dim2 is largely governed by the pulp to stone ratio, yield per plant, and fruit length. Narendra Ber Sel1 genotype was positively associated (Fig. 3) with fruit weight, pulp weight, and fruit breadth, suggesting greater fruit size and pulp content. This genotype also showed proximity to high stone weight, implying a trade-off between pulp and stone weight genotypes Umran and Kaithali is strongly associated with yield per plant and pulp to stone ratio, indicating its potential for high productivity and a relatively high edible-to-non edible fruit portion. This makes Umran a promising genotype for cultivation in commercial orchards where yield is a primary concern. On the other hand, Thar Bhubhraj and Gola clustered closely and aligned with the TSS (°Brix), indicating a relatively high sugar content and sweetness, which are desirable traits for table consumption and processing. Chhuhara and Kaithali, positioned in the upper-left quadrant, were characterized by greater fruit length and higher pulp to stone ratio, which may be suitable for fresh consumption, however, may not excel in the total yield or size. Thar Sevika, located in the lower-left quadrant, does not align closely with any yield or quality parameters, indicating its limited performance across the studied traits. PCA, along with correlation studies displayed that Pulp weight, pulp to stone ratio and fruit weight might be considered as principal characters for genetic improvement of yield in ber genotypes. PCA helped in identifying genotypic divergence among Umran, Thar Sevika and Narendra Ber Sel2, as superior genotypes, which performed well with respect to first two

PCs (Fig. 3) reflecting their unique trait combinations and potential for specific breeding objectives (Das *et al.,* 2022). Therefore, these genotypes could be used as a source of desirable characters in future Ziziphus hybridization programme. The ber variety Umran performed better in terms of yield, followed by Kaithali. PCA efficiently grouped the genotypes on the basis of correlated traits, highlighting Umran and Narendra Ber Sel-2 as superior for yield and size, while Thar Sevika and Chhuhara are suitable for sweetness and fruit quality. This multivariate analysis aids in the strategic selection of genotypes for breeding and cultivation in semiarid regions.

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