

Correlation Between Digital Seed Traits and Physiological Vigour Indices in Sorghum: A High-Throughput Evaluation Approach

D. POOJA¹, R. SIDDARAJU², K. V. SRIPATHY³, K. BHOJARAJA NAIK⁴ AND PARASHIVAMURTHY⁵
^{1,2&5}Department of Seed Science and Technology, University of Agricultural Sciences, ^{3&4}National Institute of Seed Science and Technology (MAU), Regional Station, GKVK, Bengaluru - 560 065
e-Mail : poojapapu47@gmail.com

AUTHORS CONTRIBUTION

D. POOJA :

Conceptualization, design, curation, tabulation of results manuscript writing and data analysis

R. SIDDARAJU :

Conceptualization, design, manuscript editing, guidance and supervision

K. BHOJARAJA NAIK;
PARASHIVAMURTHY &

K. V. SRIPATHY :

Guidance, critical feedback, helped to shape the research and review manuscript

Corresponding Author :

D. POOJA

Received : November 2025

Accepted : December 2025

ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is a vital cereal crop cultivated extensively in arid and semi-arid regions due to its adaptability to harsh environmental conditions. Among various seed quality parameters, seed vigour plays a crucial role in predicting the potential field performance of seeds under diverse environmental conditions. Rapid and accurate assessment of seed vigour is essential for improving crop establishment and productivity of seed lots. This study investigated the correlation between digital seed morphometric traits and physiological vigour indices in fifteen sorghum seed lots, aiming to establish a high-throughput and non-destructive evaluation method. Seed morphometric traits such as seed area, length, width and diameter were recorded through image analysis, while physiological vigour parameters included germination percentage, seed vigour index I (SVI I) and electrical conductivity (EC). Correlation analysis revealed that seed density ($r=0.817$), width ($r=0.774$), area ($r=0.615$), thickness ($r=0.533$) were positively associated with germination percentage and SVI I and negatively correlated with EC indicating that larger dense seeds tend to exhibit higher physiological vigour and lower membrane leakage. Principal component analysis (PCA) effectively reduced the trait dimensionality and highlighted parameters such as seed area, diameter, thickness and density were strongly aligned along the positive side of the F1 axis (53.93% variability), suggesting a high degree of correlation among them. Dendrogram-based hierarchical clustering grouped the seed lots into four distinct clusters, reflecting clear separation based on vigour levels and seed traits. Cluster 1 (C1) included seed lots 1, 2, 6 and 7 which were closely related, indicating high similarity in their morphometric and vigour traits. Notably seed lots 4, 12 and 15 which showed the greatest dissimilarity from all other groups. Thus, the integration of digital seed imaging with conventional vigour tests can be a reliable, efficient and scalable approach for evaluating seed quality in sorghum.

Keywords : Seed image analyser, Sorghum, Vigour, Electrical conductivity, PCA

SORGHUM (*Sorghum bicolor* L. Moench) is a highly adaptable cereal crop from Poaceae (grass) family. It ranks among the world's five major cereal grains, along with wheat, rice, maize and barley. Sorghum, often referred as the 'King of Millets' which is a nutrient-rich cereal known for its high content of carbohydrates (73.10-79.12%) and

protein (7.98-11.77%) (Widowati and Luna, 2022). It is a valuable source of essential vitamins such as vitamin B1 (0.09 mg), B2 (0.14 mg) and B3 (2.8 mg), along with minerals including iron (4.4 mg), sodium (7 mg), potassium (249 mg), calcium (28 mg) and phosphorus (287 mg). The starch in sorghum is naturally gluten-free, making

it a suitable alternative to wheat flour for individuals with celiac disease or gluten intolerance. In India, sorghum is cultivated across 3.97 million hectares, yielding a total production of 4.4 million tonnes with an average productivity of 1.0 t/ha. Karnataka is a major contributor to national sorghum output, accounting for 22% of the area (1.09 mha) and 22.9% of the total production (1.13 mT) with a productivity of 1040 kg/ha. Due to its exceptional resilience to heat and drought, sorghum is well-suited for cultivation in arid and semi-arid regions, earning the designation 'Camel of the Desert'.

High-quality seeds are essential for ensuring good field establishment, resilience under stress and efficient use of other agricultural inputs such as fertilizers and irrigation. Seed viability and vigour are critical components of seed quality, influenced by both genetic and environmental factors. There are several seed quality tests, but none is universally accepted for all kinds of seeds (Powell and Matthews, 2005). Although the standard germination test is widely used to evaluate seed quality, it primarily measures the potential of seeds to produce normal seedlings under ideal conditions. However, this test does not reliably predict seed performance under field conditions or detect early signs of seed deterioration (McDonald, 1980). Additionally, it fails to distinguish between strong and weak seedlings in seed lots with high viability, limiting its ability to assess true physiological vigour.

To overcome these limitations, alternative vigour testing methods have gained attention, offering more sensitive assessments of seed performance. One such approach is seed image analyser, which enables non-destructive evaluation of seed morphometric traits. These traits are often associated with seed size, reserve content and structural integrity, which influence seedling establishment and early growth. Similarly, the conductivity test determines the degree of seed vigour by measuring the electrolyte leakage into the water in which seeds are steeped. Compared to low-vigour seeds, high-vigour seeds are better at repairing damage and reorganizing their damaged membranes. The test has been used extensively in

agriculture to assess the vigour and viability of seeds in a variety of crops (AOSA, 1991).

Recent investigations have demonstrated a substantial correlation between morphometric features and electrical conductivity (EC). Smaller or structurally damaged seeds are often associated with higher EC values, which indicate less vigour. Electrical conductivity (EC) and morphometric characteristics have been shown to significantly correlate in recent studies. Higher EC values, which indicate decreased vigour, are frequently seen in seeds that are smaller or structurally damaged. Measuring a seed's length, width, density, thickness and area is known as seed morphometric analysis. The morphometric changes like seed perimeter, area, diameter, roundness, roughness, elongation and compactness are help full in varietal identification. Numerous crops have been evaluated using image analyzer to distinguish between cultivars (Geetha *et al.*, 2011; Grillo *et al.*, 2011 and Daniel *et al.*, 2012). Further, seed morphometric characters changing after ageing can be effectively captured by image analysis which in turn would indicate the rate of seed deterioration (Nethra, 2005 and Renuka *et al.* (2022)). According to Sumathi & Balamurugan (2013) and Sri & Nagarajappa (2023), this method provides information that can be retrieved visually more quickly and repeatedly. With this background study was conducted to analyse different seed morphometric traits of sorghum and its correlation with other vigour tests for cataloguing high and low vigour sorghum seed lots.

MATERIAL AND METHODS

Seed Material : Fifteen sorghum seed lots of different varieties of acceptable germination percentage were procured from Indian Institute of Millet Research, Hyderabad.

Standard Seed Germination Test : The germination test was conducted as per ISTA rules, 2024 in the laboratory by using between-paper method. Hundred seeds were randomly selected from each seed lot in four replications and placed equidistantly on the paper towel, they were further rolled and kept in a germination chamber with a temperature of 25 ± 1 °C

TABLE 1
Seed lots of sorghum used for the study

CSV 15 R01	(RABI 2023)
CSV 48	(R 2024)
CSH 24 MF	(R 2024)
CSV 29 R	(R 2024)
CSV 38 F	(R 2023)
CSV 41	(R 2024)
CSV 32 F	(R 2024)
CSV 21 F	(R 2024)
CSV 15 R 12	(R 2023)
CSH 43 MF	(R 2024)
CSV 32 F	(R 2023)
467 A	(R 2024)
CSV 38 F	(R 2024)
PGPS 2	(R 2024)
COFS 29	(Kharif 2024)

and 90 per cent RH. The first count and the final count of the germinated seedlings were taken on the 4th and 10th day, respectively and the percentage of germination was expressed based on the number of normal seedlings present.

Seed Vigour Index : The seed vigour index was calculated as per the formula given by Abdul-Baki & Anderson, 1973.

$SVI-I = \text{Germination (\%)} \times [\text{Shoot length (cm)} + \text{Root length (cm)}]$

Electrical Conductivity Test : The electrical conductivity of the leachate from seeds of each seed lot was determined by EC test as per ISTA rules, 2024. 200 seeds in 4 replicates of 50 seeds each were soaked in 50 ml of deionized water for 24 hours and held in a germinator at 20°C. After 24 hours, the electrical conductivity of leachates was determined using a conductivity meter and conductivity per gram of seed weight was calculated ($\mu\text{Scm}^{-1}\text{g}^{-1}$) and recorded.

$$\text{Conductivity } (\mu\text{S cm}^{-1} \text{ g}^{-1}) = \frac{\text{Conductivity reading } (\mu\text{S cm}^{-1}) - \text{Background reading}}{\text{Weight of replicate (g)}}$$

Seed Morphometric Traits : This study used a Biovis seed image analyzer, a less time-consuming image processing application that was maintained at the Seed Technology Research Unit, AICRP on Seed (Crops), UAS, GKVK, Bengaluru. Ten seeds from each seed lot were taken with ten replications in order to assess the following seed morphological characteristics: length (mm), width (mm), area (mm^2), diameter (mm), density (gray), thickness and compactness (Fig. 1).

Length (mm) : The maximum linear distance measured along the longest axis of the seed.

Width (mm) : The maximum distance measured perpendicular to the length, representing the seed's breadth.

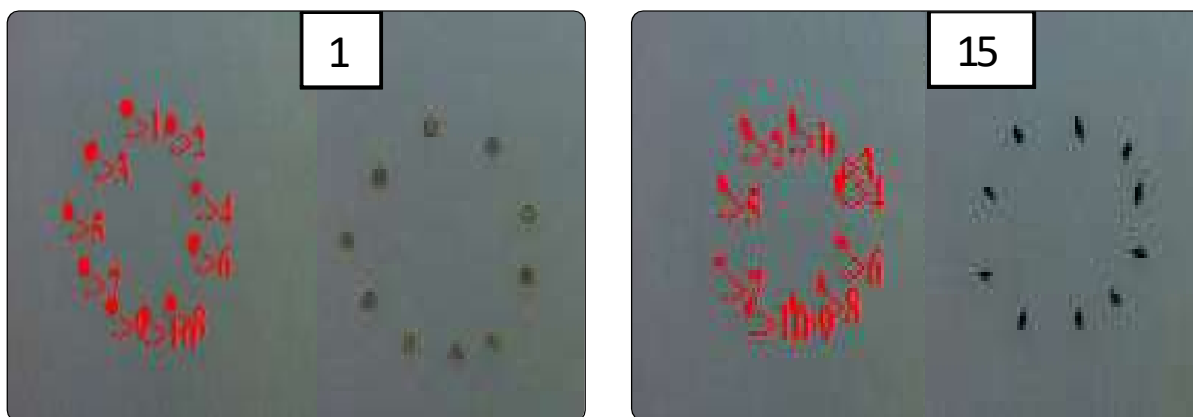


Fig. 1 : Seed image analysis

Area (mm^2) : The total two-dimensional surface occupied by the seed, calculated from its outline.

Diameter (mm) : The straight-line distance across the seed passing through its center, usually measured for near-circular shapes.

Density (gray) : It is the measure of mass per unit volume of a seed, reflecting how compactly its tissues particularly the endosperm and embryo are packed.

Thickness (mm) : The depth or vertical dimension of the seed measured perpendicular to its surface.

Compactness : A shape descriptor indicating how closely the seed resembles a perfect circle, based on the relationship between area and perimeter.

Statistical Analysis : The data collected from the experiment were analysed statistically by following the procedure suggested as by Panse and Sukhatme (1967). Whenever 'F' test was found significant, the critical difference (CD) values were calculated and the mean were compared at five per cent. Correlation was studied among vigour tests using Pairwise Pearson's correlation coefficient, regression analysis and Principal component analysis using statistical softwares.

RESULTS AND DISCUSSION

Analysis of Seed Morphometric and Physiological Traits

A significant variation was observed among the fifteen sorghum seed lots with respect to different morphometric parameters such as area, length, width, diameter, density, roundness, compactness and thickness (Table 2). These physical traits were evaluated using a seed image analyzer, providing high-throughput and precise measurements. Seed area ranged from 7.7 mm^2 (COFS 29 K24) to 13.38 mm^2 (CSV 38 F R23) indicating moderate variability in seed size. The seed length varied from 3.5 mm (CSV 15 R01 R23) to 4.82 mm (CSV 48 R24), while width ranged between 2.08 mm (COFS 29 K24) and 3.94 mm (CSV 48 R24). Seed diameter varied from 2.96 mm to 4.12 mm,

reflecting diversity in seed shape and filling among genotypes. Seed density showed the widest range among all parameters, from 18.63 (COFS 29 K24) to 81.42 (CSV 15 R12 R23), suggesting that COFS 29 K24 had exceptionally low density compared to other seed lots. In contrast, CSV 15 R12 (R23) and CSV 48 (R24) exhibited the highest densities, indicating well-filled and heavier seeds. Roundness values ranged from 0.62 to 0.99, showing that most genotypes produced nearly spherical seeds except for CSV 15 R12 (R23), which showed relatively irregular shape. Compactness varied between 12.43 and 18.63, indicating that seed surface compactness differed notably among genotypes. Thickness ranged from 2.32 mm to 3.97 mm, with CSV 48 (R24) recording the maximum and COFS 29 (K24) the minimum.

The results of physiological seed quality evaluation among the fifteen sorghum seed lots revealed significant variations in germination percentage, electrical conductivity and Seedling Vigour Index I indicating clear genotypic differences in vigour and viability. Germination percentage ranged from 76.5% (COFS 29) to 99.5% (CSV 48). CSV 48 (R24) recorded the highest germination, followed by CSV 41 (R24) and PGPS 2 (R24), whereas COFS 29 (K24) exhibited the lowest germination. Electrical conductivity values varied widely from 31.35 $\mu S/cm$ (CSV 48) to 91.16 $\mu S/cm$ (CSV 32 F), with higher EC values indicating greater membrane leakage and lower vigour. The inverse relationship between EC and germination suggests that seed lots with low EC values, such as CSV 48 (R24) and CSV 41 (R24), maintained better membrane integrity and physiological quality. Seedling Vigour Index I ranged from 1499 (COFS 29) to 3006 (CSV 48), with a mean CV of 4.3%, reflecting substantial variation among genotypes. CSV 48 (R24) exhibited the highest vigour, followed by CSV 41 (R24) and CSV 15 R01 (R23), while COFS 29 (K24) showed the poorest performance, corroborating its low density and smaller seed size from morphometric data.

Larger seed area was generally associated with higher germination percentage and seedling vigour index (Varga *et al.*, 2012 and Kesavan *et al.*, 2013). For

TABLE 2
Analysis of seed morphometric and physiological traits

Seed lots	Area (sq mm)	Length (mm)	Width (mm)	Diameter (mm)	Density (gray)	Round Ness	Compact Ness	Thickness (mm)	Germination %	EC ($\mu\text{Scm}^{-1}\text{g}^{-1}$)	SVII
CSV 15 R01 (R23)	8.52	3.50	2.86	3.15	72.99	0.88	14.73	2.55	95.50	58.81	2808
CSV 48 (R24)	12.62	4.82	3.94	4.12	80.86	0.96	16.82	3.97	99.50	31.35	3006
CSH 24 MF (R24)	11.79	4.05	3.73	3.62	77.51	0.99	12.76	3.78	91.00	55.74	2566
CSV 29R (R24)	11.31	4.47	3.83	3.69	80.28	0.88	16.73	3.62	95.00	44.12	2281
CSV 38 F (R23)	13.38	4.53	3.78	3.87	76.46	0.96	13.05	3.83	96.50	45.94	2671
CSV 41 (R24)	12.21	4.25	3.66	3.59	79.76	0.99	12.76	3.72	98.00	47.04	2848
CSV 32 F (R24)	12.31	4.10	3.77	3.65	76.10	0.98	12.43	3.74	94.00	65.60	2768
CSV 21F (R24)	8.34	3.67	2.78	3.17	75.82	0.77	18.63	2.57	87.00	59.79	2270
CSV 15 R12 (R23)	8.20	3.86	3.34	3.21	81.42	0.62	17.95	2.32	92.50	60.03	2611
CSH 43MF (R24)	12.08	4.17	3.77	3.67	75.54	0.92	15.50	3.59	92.50	62.30	2494
CSV 32 F (R23)	11.75	3.94	3.67	3.46	75.66	0.99	12.71	3.80	92.50	91.16	2339
467 A (R24)	11.83	4.24	3.71	3.71	76.29	0.98	12.53	3.62	94.50	75.98	2670
CSV 38F (R24)	9.15	4.16	3.40	3.23	77.45	0.76	12.48	2.44	95.50	57.60	2686
PGPS 2 (R24)	11.96	4.42	3.32	3.57	67.28	0.99	12.76	3.46	97.00	71.79	2621
COFS 29 (K24)	7.70	4.46	2.08	2.96	18.63	0.84	15.10	2.32	76.50	53.68	1499
S.Em \pm	0.31	0.14	0.12	0.60	0.02	0.43	0.11	2.03	3.10	77.32	
CD (5%)	0.92	0.44	0.35	1.81	0.05	1.3	0.32	6.11	9.34	233.07	
CV (%)	3.98	3.95	4.73	1.17	2.66	4.23	4.53	3.77	4.46	4.3	

instance, CSV 48 (R24) with a seed area of 12.62 mm² showed the highest germination (99.5%) and SVI I (3006), confirming the positive role of seed size in seedling vigour. Genotypes with larger diameters such as CSV 48 (R24), CSV 15 R01 and CSV 38F exhibited higher seedling vigour. This suggests that seed diameter, indicative of greater seed volume and reserve material, contributes positively to early seedling growth (Zhang *et al.*, 2014 and El-abady, 2015). Genotypes with higher seed density recorded relatively lower electrical conductivity (EC) values indicating better membrane integrity and seed vigour. Conversely, genotypes with lower density such as COFS 29 (18.63) showed a high EC value of 53.68 $\mu\text{S cm}^{-1} \text{g}^{-1}$ and low SVII (1499), reflecting poor seed vigour. Larger and denser seeds like CSV 48 (R24) and CSV 29R had lower EC values, whereas lighter and smaller seeds like COFS 29 and CSV 32F (R23) had higher EC values, suggesting poor vigour. According to Peterson *et al.* (1995), flat seeds are not very prone to mechanical damage. SVI I and seed morphometric characteristics such as area, diameter and density showed a definite tendency of positive

correlation, but EC values showed a clear pattern of negative correlation. This demonstrates how well image-based seed attributes may be integrated to predict physiological seed performance.

Correlation Analysis of Seed Morphometric and Physiological Traits

A correlation heatmap was constructed to visualize the relationships among various seed morphometric traits (area, diameter, compactness, etc.) and physiological vigour parameters such as germination percentage, electrical conductivity and seed vigour index I (Fig. 2). The intensity and colour gradient of the blocks represent the strength and direction of the Pearson correlation coefficients, ranging from strong positive (red) to strong negative (blue) associations. Traits such as seed area, diameter and thickness showed a strong positive correlation with germination percentage and Seed Vigour Index I indicating that larger and well-developed seeds tend to have better germination capacity and produce more vigorous seedlings. These traits also exhibited a negative correlation with electrical conductivity suggesting that

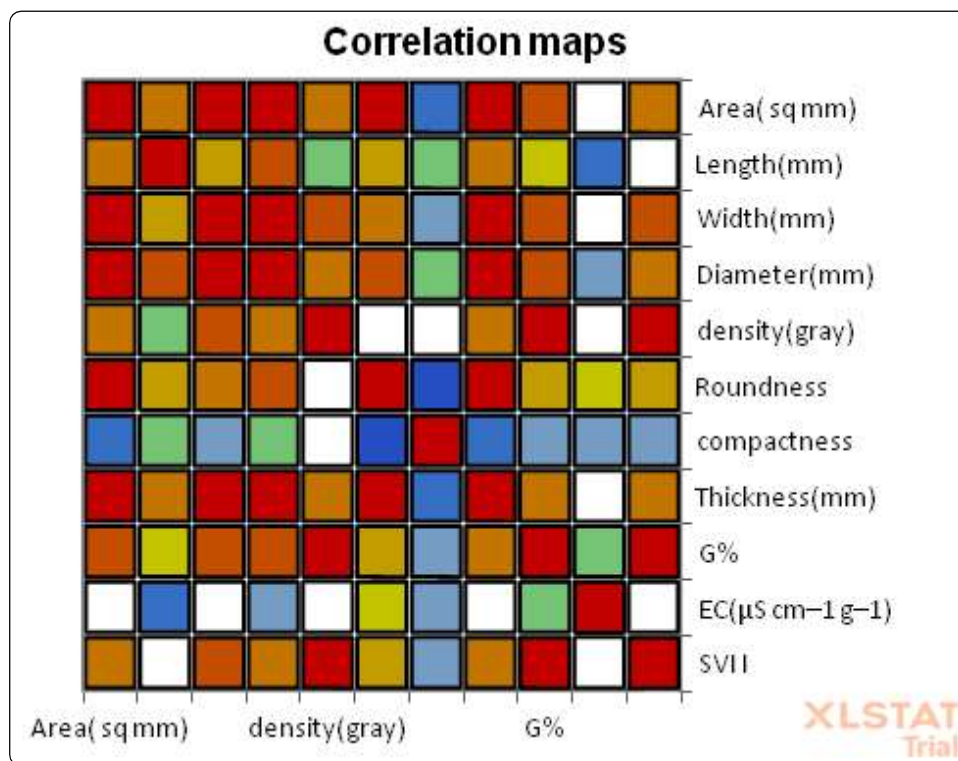


Fig. 2 : Correlation analysis of seed morphometric traits and physiological traits

seeds with greater physical integrity and size had lower membrane leakage and hence better vigour. Seed density also showed highly positive correlation with germination ($r=0.817$) and SVI I ($r=0.801$) and negative correlation with EC, reinforcing its importance in seed quality evaluation. Conversely, traits like compactness and roundness showed weaker or inconsistent relationships with physiological parameters, indicating limited predictive value for seed vigour. The inverse relationship of EC with key morphometric traits and direct relationship of SVI I with seed size and density confirm that seed image analysis can serve as a reliable, non-destructive method for assessing seed quality. These findings highlight that integrating morphometric traits derived from image analysis with physiological vigour tests such as EC and SVI I provides a more comprehensive and accurate evaluation of seed vigour potential across genotypes. Comparable outcomes for seed vigour, specifically the SVI and EC, as well as seed morphometry were reported in maize (Peterson *et al.*, 1995 and Varga *et al.*, 2012).

Regression Analysis of Seed Morphometric Traits

Further regression analysis conducted between different seed morphometric traits and physiological parameters such as germination percentage, electrical conductivity (EC) and seedling vigour index I (Table 3) revealed varying levels of association among the measured variables. Among the morphometric traits, seed density exhibited the strongest and most significant relationship with physiological traits ($R^2 = 0.698$; $F = 8.494$ and $p = 0.003$), indicating that seeds with higher density tend to possess higher germination and vigour, and lower EC values. Width

($R^2 = 0.609$ and $p = 0.013$) also showed a significant positive correlation, suggesting that broader seeds contribute to enhanced physiological performance, likely due to better embryo development and nutrient reserves. Length ($R^2 = 0.425$ and $p = 0.096$) and area ($R^2 = 0.408$ and $p = 0.111$) showed moderate associations, implying that while size contributes to seed vigour, its influence is secondary to thickness and density.

Thickness ($R^2 = 0.318$ and $p = 0.222$), roundness ($R^2 = 0.150$ and $p = 0.600$) and compactness ($R^2 = 0.247$ and $p = 0.354$) displayed weaker, non-significant relationships, indicating that shape parameters play a minor role in determining physiological quality. Overall, the analysis highlights that larger, denser and more dimensionally developed seeds are physiologically more vigorous, whereas irregular or smaller seeds tend to exhibit reduced germination and higher EC, reflecting membrane leakage and poor viability. These findings are consistent with earlier reports in cereals where morphometric attributes, especially seed size and density, were found to be reliable indicators of seed vigour and storage potential.

Seed density serves as an important physical indicator of seed quality, closely linked with seed filling, integrity and viability. The present regression analysis demonstrated a strong positive relationship between seed density and seed vigour parameters, consistent with earlier findings in cereal crops (Adebisi *et al.*, 2013 and Singh *et al.*, 2018). The close clustering of data points (Fig. 3) along the regression line indicated that seed density can effectively predict the physiological performance of sorghum seeds

TABLE 3
Regression analysis of seed morphometric traits

	Area (sq mm)	Length (mm)	Width (mm)	Diameter (mm)	Density (gray)	Roundness	Compactness	Thickness (mm)
R^2	0.408	0.425	0.609	0.495	0.698	0.150	0.247	0.318
F	2.525	2.708	5.713	3.596	8.494	0.649	1.204	1.712
Pr > F	0.111	0.096	0.013	0.050	0.003	0.600	0.354	0.222

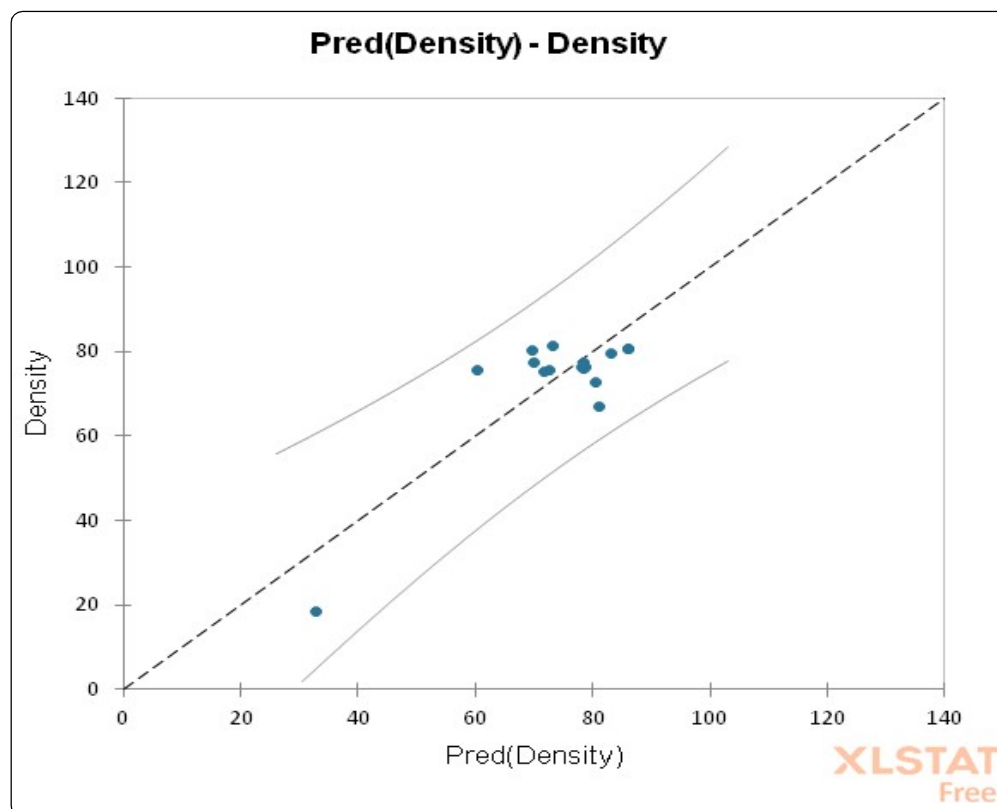


Fig. 3 : Predicted regression model for seed density

during germination and early seedling growth. Higher-density seed lots were associated with higher germination percentage and vigour indices, which can be attributed to better embryo development, nutrient reserves and metabolic efficiency during germination. Conversely, low-density seeds, often resulting from poor grain filling or mechanical damage, exhibited reduced physiological vigour and higher electrolyte leakage, as indicated by elevated EC values.

Principal Component Analysis (PCA)

Principal component analysis was employed to elucidate the multivariate relationships among seed morphometric characteristics and physiological seed quality parameters in 15 sorghum seedlots. The first two principal components, F1 and F2, together accounted for 72.69 per cent of the total variation observed F1 explaining 53.93 per cent and F2 contributing 18.76 per cent. This high cumulative variance indicates that the two principal axes adequately represent the variability in the dataset.

The biplot (Fig. 4) clearly delineates associations between seed physical traits and physiological vigour indicators. Morphometric parameters such as seed area, diameter, thickness, and width were strongly aligned along the positive side of the F1 axis, suggesting a high degree of correlation among them. These traits were also closely associated with germination percentage, Seed Vigour Index I indicating that genotypes possessing larger, denser seeds generally exhibited superior vigour. For instance, observations such as seedlots 1, 4 and 6 were located in the positive quadrant of both axes, signifying higher vigour potential due to favorable morphometric traits and corresponding higher germination percentage and SVI I values.

Conversely, electrical conductivity was oriented in the negative direction along the F1 axis and showed a strong inverse association with the cluster of vigour-related variables. This relationship highlights EC's effectiveness as a diagnostic indicator of membrane integrity and physiological ageing in

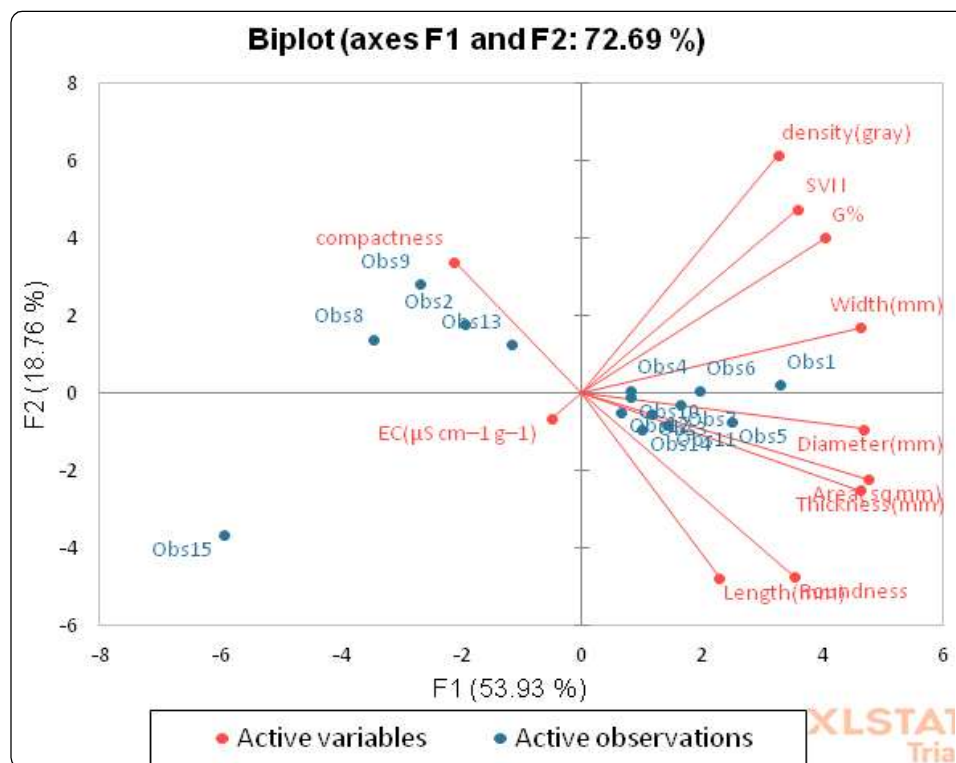


Fig. 4 : Principal Component Analysis (PCA)

seeds-genotypes with higher EC values (COFS 29) exhibited lower germination percentage and SVI I and were also morphometrically inferior, as reflected by their smaller area and diameter values.

Interestingly, traits such as compactness and roundness were projected away from the core group of vigour traits and contributed more to the variation along the F2 axis. Their spatial separation in the biplot suggests a relatively weak or independent influence on physiological seed performance, implying limited relevance as vigour predictors in sorghum. Ogunniyan (2016) has also documented the value of PC I in linking features that can be enhanced to increase agricultural productivity. According to the PCA results, the ability of seed morphometric attributes determined from image analysis to discriminate, specifically area, diameter and thickness, supported the notion that these traits are accurate indicators of seed vigour. Their positive association with germination percentage and SVI I and negative correlation with EC, demonstrated the practical utility of integrating seed image analysis with

conventional vigour tests to enhance genotype screening and seed quality evaluation.

Cluster Analysis of Sorghum Seed Lots Based on Seed Vigour Traits

The hierarchical cluster analysis grouped fifteen seed lots into four distinct clusters based on their seed vigour-related parameters, as shown in the dendrogram (Fig. 5). Cluster 1 (C1) included seedlots 1, 2, 6 and 7, which were closely related, indicating high similarity in their morphometric and vigour traits. Cluster 2 (C2) consisted of seedlots 3, 9, 10 and 14, forming another group with moderate similarity. Cluster 3 (C3) was represented by seedlots 5, 8, 11 and 13 which were more distinct from the previous two clusters, suggesting differences in seed vigour attributes. Cluster 4 (C4) comprised seedlots 4, 12 and 15 which showed the greatest dissimilarity from all other groups. Among these, seedlot 15 was highly divergent, as seen from its large dissimilarity distance as it is a fodder sorghum seedlot. The observed clustering pattern reflects considerable

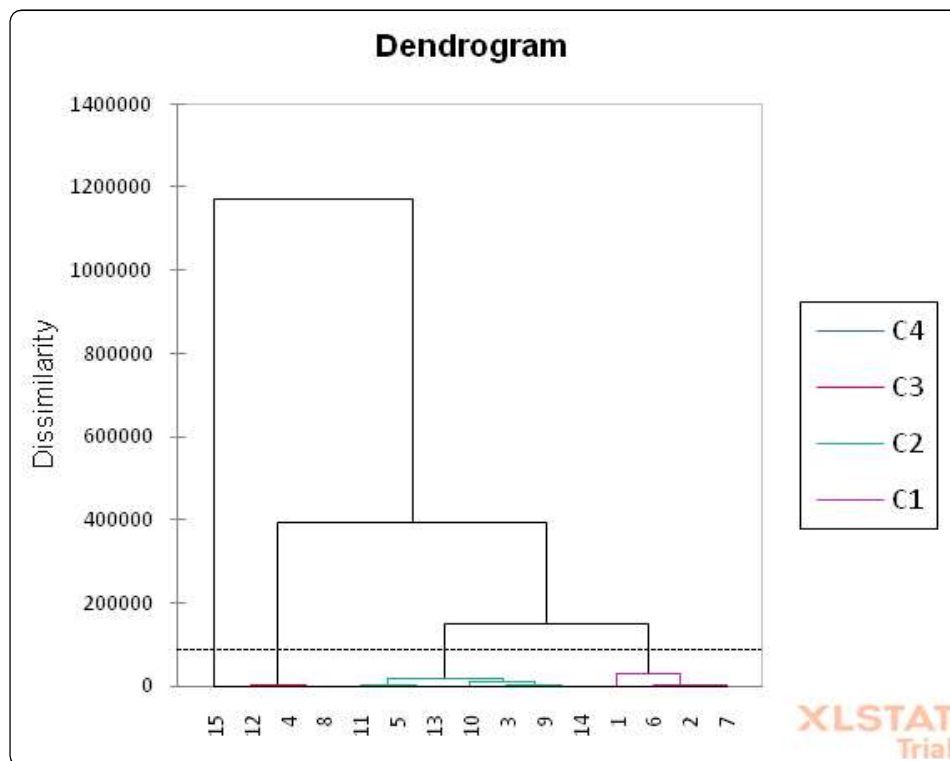


Fig. 5 : Hierarchical cluster analysis

diversity among the seedlots, which can be useful for selecting potential lines for breeding or further evaluation based on seed vigour. Similar clustering analysis done in wild rice by Adebisi *et al.*, 2013, soybean by Barbosa *et al.*, 2013, maize by Adebisi *et al.*, 2014.

This study highlights the strong correlation between digital seed morphometric traits and physiological vigour indices in sorghum. Traits like seed density, width, area and thickness were positively associated with germination and SVI I, and negatively with EC, indicating their reliability in predicting seed vigour. PCA and cluster analysis confirmed clear differentiation among seedlots, with some showing distinct morpho-physiological profiles. The combined use of digital imaging and conventional tests offers a rapid, efficient and scalable method for seed quality assessment, valuable for sorghum breeding and seed certification programs.

Acknowledgement : This research was supported by the National Institute of Seed Science and Technology, (MAU) Regional station, Bengaluru - 65, AICRP on

seed (crops), UAS, GKVK, Bengaluru - 65, Department of Seed Science and Technology. Financial support by Department of Science and Technology, KSTePs, Government of Karnataka.

REFERENCES

- ABDUL-BAKI, A. A. AND ANDERSON, J. E., 1973, Vigour determination in soybean seed by multiple criteria. *Crop Sci.*, **13** (6) : 630 - 633.
- ADEBISI, M. A., OKELOLA, F. S., AJALA, M. O., KEHINDE, T. O., DANIEL, I. O. AND AJANI, O. O., 2013, Evaluation of variations in seed vigour characters of West African rice (*Oryza sativa* L.) genotypes using multivariate technique. *Am. J. Plant Sci.*, **4** (2) : 356 - 363.
- ADEBISI, M. A., KEHINDE, T. O., PORBENI, J. B. O., ODUWAYE, O. A., BILIAMINU, K. AND AKINTUNDE, S. A., 2014, Seed and seedling vigour in tropical maize inbred lines. *Plant Breed. Seed Sci.*, **67** (1) : 87.
- AOSA., 1991, Rules for Testing Seeds. *J. Seed Technol.*, **12** : 1 - 109.

- BARBOSA, R. M., VIEIRA, B. G. T. L., FERRAUDO, A. S., CORI, J. E. AND VIEIRA, R. D., 2013, Discrimination of soybean seed lots by multivariate exploratory techniques. *J. Seed Sci.*, **35** : 302 - 310.
- DANIEL, I. O., ADEBOYE, K. A., ODUWAYE, O. O. AND PORBENI, J., 2012, Digital seed morphometric characterization of tropical maize inbred lines for cultivar discrimination. *Int. J. Plant Breed. Genet.*, **6** : 245- 251.
- EL-ABADY, M. I., 2015, Influence of maize seed size/ shape, planted at different depths and temperatures on seed emergence and seedling vigour. *Res. J. Seed Sci.*, **8** : 1 - 11.
- FATONAH, K., SULIANSYAH, I. AND ROZEN, N., 2017, Electrical conductivity for seed vigour test in sorghum (*Sorghum bicolor*). *Front. Cell Dev. Biol.*, **1** (1) : 6 - 12.
- GEETHA, V. V., BALAMURUGAN, P. AND BHASKARAN, M., 2011, Characterization of mustard genotypes through image analysis. *Res. J. Seed Sci.*, **4** : 192 - 198.
- GRILLO, O., MICELI, C. AND VENORA, G., 2011, Computerized image analysis applied to inspection of vetch seeds for varietal identification. *Seed Sci. Technol.*, **39** : 490 - 500.
- KESAVAN, M., SONG, J. T. AND SEO, H. S., 2013, Seed size: a priority trait in cereal crops. *Physiol. Plant.*, **147** : 113 - 120.
- MCDONALD, M. B. J., 1980, Assessment of seed quality. *HortScience*, **15** : 784 - 788.
- NETHRA, N., RAJENDRA PRASAD. S. AND RAME GOWDA., 2005, Varietal characterization based on seed, seedling and plant morphological traits in rice (*Oryza sativa* L.) genotypes. *Mysore J. Agric. Sci.*, **39** (3) : 362 - 367.
- OGUNNIYAN, D. J., 2016, Assessment of genetic divergence in kenaf (*Hibiscus cannabinus* L.) genotypes using agro-botanical characteristics and multivariate analysis. *SABRAO J. Breed. Genet.*, **48** (1) : 61 - 71.
- PANSE, V. G. AND SUKHATME, P. V., 1967, Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi.
- PETERSON, J. M., PERDOMO, J. A. AND BURRIS, J. S., 1995, Influence of kernel position, mechanical damage and controlled deterioration on estimates of hybrid maize seed quality. *Seed Sci. Technol.*, **23** : 647 - 657.
- POWELL, A. A. AND MATTHEWS, S., 2005, Towards the validation of the controlled deterioration vigour test for small seeded vegetables. *Seed Test. Int. Assoc. Off. Seed Anal. (ISTA) News Bull.*, **129** : 21 - 24.
- RENUKA, R., VASUDEVAN, S. N. AND SHIVAKUMAR, N., 2022, Morphological characterization of new parental lines (AxB) of rice for their production potential (*Oryza sativa* L.). *Mysore J. Agric. Sci.*, **56** (1) : 292 - 298.
- SINGH, N., THAKUR, A. K., KAUSHAL, R., MEHTA, D. K. AND BHARDWAJ, R. K., 2018, Effects of seed pelleting on seed quality of cowpea (*Vigna unguiculata* L.) during storage. *Int. J. Econ. Pl.*, **5** (2) : 76 - 79.
- SRII, V. S. AND NAGARAJAPPA, N., 2023, Seed morphometric changes influenced by accelerated ageing in contrast-coloured maize (*Zea mays* L.) genotypes. *Mysore J. Agric. Sci.*, **57** (2) : 301 - 309.
- SUMATHI, S. AND BALAMURUGAN, P., 2013, Characterization of oats (*Avena sativa* L.) cultivars using machine vision. *Pak. J. Biol. Sci.*, **16** : 1179 - 1183.
- VARGA, P., BERZY, T., ANDA, A. AND ERTSEY, K., 2012, Relationship between seed harvesting method and seed physiological quality for a number of Pioneer maize hybrids. *Maydica*, **57** : 220 - 225.
- WIDOWATI, S. AND LUNA, P., 2022, Nutritional and functional properties of sorghum (*Sorghum bicolor* (L.) Moench) based products and potential valorisation of sorghum bran. *IOP Conf. Ser. Earth Environ. Sci.*, **1024** (31) : 1 - 9.
- ZHANG, Z., LIU, Z., HU, Y., LI, W., FU, Z., DING, D., LI, H., QIAQ, M. AND TANG, J., 2014, QTL analysis of kernel-related traits in maize using an immortalized F2 population. *PLoS One*, **9** : e89645. doi: 10.1371/journal.pone.0089645.