Received: 02 Jun 2025 | Revised: 23 Jul 2025 | Accepted: 25 Jul 2025

Electronic Journal of Plant Breeding

Research Note

Profiling of proximate composition in red sorghum (*Sorghum bicolor* L. Moench) genotypes for nutritional enhancement

J. Shanalin[1], R. Chandirakala[1]* and K. Chandrakumar[2]

[1]Department of Genetics and Plant Breeding, TNAU, Coimbatore-641003, India.
[2]Department of Renewable Energy Engineering, TNAU, Coimbatore-641003, India.
***E-Mail:** chandirakala2009@gmail.com

Abstract

The present study aimed to evaluate the nutritional variability and genetic advancement across F_3 and F_4 generations in three red sorghum crosses: Paiyur 2 × IS 20603, Paiyur 2 × IS 21731, and CO 32 × Paiyur 2. Key nutritional traits including protein, fat, fibre, ash, moisture, and carbohydrate contents were assessed using descriptive statistics, correlation analysis, and principal component analysis (PCA). Comparative analysis revealed significant improvement in mean protein and fat contents from F_3 and F_4 generations, with Cross 2 (Paiyur 2 × IS 21731) recording the highest protein (11.45%) and fat (5.66%) values, indicating strong transgressive segregation and potential for nutritional enhancement. Trait ranges broadened in the F_4 generation, reflecting greater genetic variability, while standard deviations and coefficients of variation remained within acceptable limits, demonstrating controlled variability and increased trait stability. Correlation heatmaps revealed strong positive relationships among protein, fat, and carbohydrate contents, and strong negative correlations between ash and fibre, and between ash and carbohydrate. These associations underscored the interdependence and trade-offs among nutritional traits, providing critical insights for selection strategies. PCA results indicated that the first two principal components (PC1 and PC2) explained 95.56% of the total variation, with ash and carbohydrate being the most discriminating traits. Traits like protein, fat, and moisture were tightly clustered, confirming their co-expression. Cross 2 emerged as a superior cross for nutritional improvement, while Crosses 1 and 3 exhibited better early trait stability. Overall, the study provided a robust framework for selecting nutritionally rich, genetically stable red sorghum lines for future crop improvement programs.

Keywords: Red sorghum, proximate composition, correlation, Principal Component Analysis

Malnutrition, characterized by protein-energy deficiencies and micronutrient insufficiencies, remains a major dietary issue in many developing nations, including India (Kurmi *et al.,* 2023). India also faces significant challenges in ensuring food security for its rapidly growing population. With increasing concerns over climate change and declining soil fertility, identifying nutritionally rich and climate-resilient crops is crucial for sustainable agriculture. To address this, it is essential to explore local biodiversity, including underutilized crops such as red sorghum (*Sorghum bicolor*). Assessing the nutritional composition of red sorghum genotypes will provide valuable data that can help in promoting their utilization at both industrial and household levels (Xiong *et al.,* 2019). This, in turn, will contribute to efforts aimed at improving food availability, dietary diversity, and nutritional security across the country.

Sorghum is an essential food crop in India, particularly in semi-arid and drought-prone regions, where it serves as a staple food source(Manonmani *et al.,* 2002). It is a dual-purpose crop, used for human consumption, livestock feed, and industrial applications, including alcohol production and biofuel manufacturing

(Awika *et al.,* 2005). Due to its high drought tolerance, sorghum can be cultivated with minimal rainfall, making it an excellent alternative to water-intensive cereals such as rice and wheat(Nirosh *et al.,* 2021). According to global agricultural reports, sorghum is grown on approximately 46 million hectares worldwide, with an annual production of around 60 million tonnes (Ndondo 2023). This hardy crop plays a crucial role in food security, particularly in regions where other major cereals struggle to thrive (Edeoga and Gomina 2001). Nutritionally, red sorghum is a valuable source of carbohydrates, proteins, dietary fiber, and essential nutrients. The protein content of sorghum is comparable to that of wheat and maize, although lysine is its most limiting amino acid. Additionally, sorghum contains B-complex vitamins and β-carotene, but their levels vary depending on environmental conditions (Ihekoronye and Ngoddy 1985). Despite its rich nutritional profile, the limited digestibility of its protein and the presence of antinutritional factors have hindered its widespread adoption in mainstream diets. Conducting a proximate analysis of red sorghum genotypes will provide crucial insights into its macronutrient composition, including moisture, protein, fat, fiber, ash, and carbohydrate content, which will aid in improving its processing and utilization (Jimoh and Abdullahi 2017).

Proximate analysis is a fundamental method for evaluating the nutritional quality of food grains. Understanding the variations in macronutrient composition among different sorghum genotypes is essential for selecting varieties with superior nutritional attributes (Henley *et al.,* 2010). This information will support the development of nutrient-rich sorghum-based food products that cater to evolve consumer preferences and industry demands. Additionally, as India moves towards promoting millets and other indigenous grains under initiatives such as the International Year of Millets, studies like this play a crucial role in enhancing the market potential of sorghum by demonstrating its nutritional advantages (Mohod *et al.,* 2023). This study focused on the proximate analysis of quality traits in selected red sorghum genotypes grown under Indian agro-climatic conditions. By assessing their macronutrient composition, this research aimed to provide comprehensive data that will support the increased utilization of red sorghum in food products. The findings will not only contribute to dietary diversification but also help position red sorghum as a viable alternative to mainstream cereals, thereby strengthening India's food security efforts and promoting sustainable agriculture.

Sorghum grains from F_3 and F_4 generation derived for the crosses namely Paiyur 2 x IS 20603, Paiyur 2 x IS 21731 and CO 32 x Paiyur 2 were used for the proximate analysis. The experiment was conducted using a randomized complete block design (RCBD) with 10 genotypes in cross 1, 10 genotypes in cross 2 and 20 genotypes in cross 3 in three replications during the summer season of 2023 and 2024 conducted at Department of Millets, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. Qualitative traits including moisture content (%), Protein (%), fat (%), fibre (%), Ash (%), and carbohydrate (%) were recorded in this experiment. The samples were sorted, cleaned and ground separately using a laboratory-scale mill (Vibrating Cup Mill (VCM-100)) at medium grinding speed to minimize excessive heat generation, which could affect phenolic compounds. The final sorghum flour was stored in hermetically sealed containers at 4°C to prevent moisture absorption and oxidative degradation before further analysis. The descriptive statistics were analyzed using TNAU software (Version 0.1.0) and the correlation (package – corrplot) and Principal Component Analysis (PCA) were statistically analyzed using R software (package – factoextra).

(A) Determination of Moisture Content:
Moisture Content was determined by weighing three grams of the samples into the moisture cans (Sadasivam 1996). The weight of the moisture loss was determined and expressed in percentage. The procedure was repeated for all the samples. It was calculated as shown below:

$$Moisture\ (\%) = \frac{W1 - W2}{W1}\ x\ 100$$

Where,
W1 = weight (g) of sample before drying
W2 = weight (g) of the sample after drying.

(B) Determination of Fat content (Ether extract):
The fat content of the samples was determined by the continuous solvent extraction method using a soxhlet apparatus (Sadasivam 1996). The weight of the fat (oil) extracted were determined and calculated in percentage as follows:

$$Fat\ (\%) = \frac{W1 - W2}{W}\ x\ 100$$

Where,
W2 = weight of the flask and oil extracts
W1 = weight of empty extraction flask and W = weight of sample

(C) Determination of crude fiber:
The crude fiber was determined by the Wende method (Sadasivam 1996). The crude fiber contents were calculated in percentage.

$$Fibre\ (\%) = \frac{\text{Amount of crude fibre}}{Weight\ of\ the\ sample}\ x\ 100$$

(D) Determination of Protein:
The protein content was determined by the Lowry method (Sadasivam 1996) using Folin-Ciocalteu reagent. The absorbance at 750 nm was taken for samples using Cary 60 Spectrophotometer version 5.1.3.1042 and the protein content in the samples was calculated using the standard curve.

$$Protein\ (\%) = \frac{\text{Absorbance of sample} - \text{Absorbance of blank}}{\text{Slope of standard curve}}\ x\ \text{Dilution factor}$$

(E) Determination of Total ash:
The ash content was determined using the furnace incineration gravimetric (Sadasivam 1996). The weight of the ashes was obtained and calculated in percentage.

$$Ash\ (\%) = \frac{W3 - W2}{W1}\ x\ 100$$

Where,
W2 = original weight of crucible + sample
W3 = weight of crucible + crucible content after ashing
W = weight of the sample

(F) Determination of carbohydrate:
The sample was hydrolyzed with dilute acid, which then reacted with anthrone reagent in the presence of concentrated sulfuric acid under heating (usually at 90–100°C for 10 minutes). This reaction resulted in the formation of a blue-green complex whose intensity was measured spectrophotometrically (Cary 60 Spectrophotometer version 5.1.3.1042) at 620 nm (Sadasivam 1996).

The comparative analysis of nutritional traits across F_3 and F_4 generations in three red sorghum crosses (Paiyur 2 × IS 20603, Paiyur 2 × IS 21731, and CO 32 × Paiyur 2) revealed prominent trends in trait improvement and genetic stability, reflecting genetic advancements in nutritional traits and aligning with previous studies (Abah *et al.,* 2020, Nayak *et al.,* 2023). Across all crosses, an increase in mean values was observed for protein and fat content from F_3 to F_4 generations, indicating genetic progress and potential transgressive segregation. The highest protein content in the F_4 generation (11.45%) was recorded in Cross 2, along with the highest fat content (5.66%), suggesting the superiority of this cross for nutritional enhancement. These values aligned with the range reported for protein and fat contents in sorghum brans and whole flours by previous studies (Adebo and Kesa 2023), which documented protein levels between 10.02% to 14.00% and fat content up to 5.71%. This similarity suggested that the genetic improvements observed in the F_4 generation, particularly in Cross 2, have successfully enhanced the nutritional profile to a level comparable with high-value sorghum fractions such as bran and whole flour. The range of trait values extended in F_4 for most characters, particularly carbohydrate and moisture content, reflecting greater genetic variability, which is beneficial for selection. Similar findings were also reported by (Falmata *et al.,* 2013) which investigated the soaking and dehulling effects on chemical composition, tannins and mineral elements content of five local varieties of sorghum. Standard deviation (SD) values, although slightly improved in some traits, remained within acceptable limits, indicating that variability is still under control. Interestingly, standard error (SE) values were gradually low in both generations, confirming the reliability and precision of the data. Coefficient of variation (CV%) values generally decreased from F_3 to F_4, especially for significant traits such as protein, moisture, and carbohydrate content, suggesting that environmental influence decreased and genetic control increased over generations. These observations aligned with findings from previous studies, which reported significant genetic variability among sorghum accessions for grain quality traits, including protein, moisture, and carbohydrate content. For instance, a study on lowland sorghum accessions from southern Ethiopia found considerable variability in protein content, ranging from 7.99% to 17.80%, and moisture content, indicating the potential for genetic improvement through selection (Gebre *et al.,* 2024). Another study highlighted the importance of multiple trait selection strategies to enhance genetic gains for yield and yield components in sorghum breeding programs (Andiku *et al.,* 2022).

Among the three red sorghum crosses studied, Cross 2 (Paiyur 2 × IS 21731) recorded the highest mean values for key nutritional traits such as protein, fat, and carbohydrate content in both F_3 and F_4 generations. However, this cross also exhibited wider ranges and relatively higher standard deviations in the F_4 generation for some traits, indicating that while it holds great genetic potential for nutritional enhancement, a certain degree of trait variability still exists. This variability suggested that further selection and advancement were needed to stabilize these desirable traits. In contrast, Cross 1 (Paiyur 2 × IS 20603) and Cross 3 (CO 32 × Paiyur 2) showed comparatively moderate mean values but demonstrated greater consistency in performance, particularly in traits like moisture and ash content. These crosses displayed narrower trait ranges, lower standard deviations, and reduced coefficients of variation, indicating better early stabilization and more uniform expression of certain nutritional characteristics.

In the F_3 generation of red sorghum, the correlation heatmap revealed important interrelationships among various nutritional traits (**Fig. 1**). A strong positive correlation was observed between protein and fat content (r = 0.81), as well as between protein and fibre (r = 0.81), indicating that F_3 genotypes with higher protein levels also tend to have increased fat and fibre content. This suggested that selecting for higher protein content may simultaneously enhance fat and fibre levels, which could be beneficial for developing nutrient-dense sorghum varieties (Gebre *et al.,* 2024, Rhodes *et al.,* 2017). Similarly, moisture and carbohydrate contents exhibited a very strong positive correlation (r = 0.98), suggesting that carbohydrate-rich grains generally contain more moisture. This close association implied that improving carbohydrate content may also affect the grain's moisture retention, potentially influencing grain texture and

Table 1. Descriptive statistics of nutritional traits in three red sorghum crosses across F_3 and F_4 generations

	Mean		Range		SD		SE		CV (%)	
Characters	F_3	F_4	F_3	F_4	F_3	F_4	F_3	F_4	F_3	F_4
Cross 1 (Paiyur 2 x IS 20603)										
Moisture (%)	3.54	3.99	3.13-4.50	3.11-5.24	0.50	0.80	0.06	0.04	2.74	1.66
Protein (%)	5.14	8.35	4.19-8.62	5.67-9.59	1.54	1.31	0.06	0.04	1.97	0.87
Fat (%)	2.24	3.50	2.13-2.46	2.38-5.10	0.11	0.90	0.02	0.03	1.93	1.92
Fibre (%)	1.14	1.51	1.13-1.33	1.23-1.67	0.05	0.13	0.01	0.07	1.64	8.33
Ash (%)	1.15	1.40	1.13-1.23	1.15-1.59	0.03	0.15	0.05	0.02	6.88	2.86
Carbohydrate (%)	64.50	67.41	44.45-113.44	46.00-115.85	17.81	17.61	0.93	0.18	2.50	0.47
Cross 2 (Paiyur 2 x IS 21731)										
Moisture (%)	3.55	3.90	3.10-4.66	3.14-5.24	0.53	0.76	0.05	0.04	0.15	1.73
Protein (%)	6.03	8.59	4.20-8.93	6.31-11.45	1.73	1.63	0.05	0.05	0.14	0.94
Fat (%)	2.25	4.20	2.14-2.49	2.33-5.66	0.11	1.13	0.02	0.05	0.06	1.91
Fibre (%)	1.15	1.54	1.12-1.33	1.27-1.77	0.08	0.15	0.14	0.07	0.04	7.61
Ash (%)	0.18	1.30	1.10-1.35	1.12-1.57	0.03	0.15	0.05	0.02	0.15	2.29
Carbohydrate (%)	78.38	81.67	62.94-96.31	67.45-96.31	9.28	8.50	0.73	0.35	2.17	0.74
Cross 3 (CO 32 x Paiyur 2)										
Moisture (%)	3.54	3.80	3.13-4.47	3.11-5.24	0.44	0.70	0.05	0.05	2.40	2.26
Protein (%)	6.36	8.24	5.51-12.62	5.67-12.65	2.36	1.75	0.06	0.08	1.81	1.73
Fat (%)	2.30	3.61	2.13-3.30	2.08-5.66	0.26	1.07	0.02	0.04	1.71	1.97
Fibre (%)	1.20	1.53	1.12-1.77	1.23-1.77	0.16	0.14	0.02	0.05	2.29	6.08
Ash (%)	1.20	1.32	1.11-1.60	1.12-1.59	0.12	0.16	0.05	0.03	6.88	3.61
Carbohydrate (%)	60.40	69.52	31.24-86.16	39.58-83.57	15.26	11.41	0.39	0.53	1.13	1.33

SD-Standard deviation, SE-Standard error and CV- coefficient of variation at 5 %

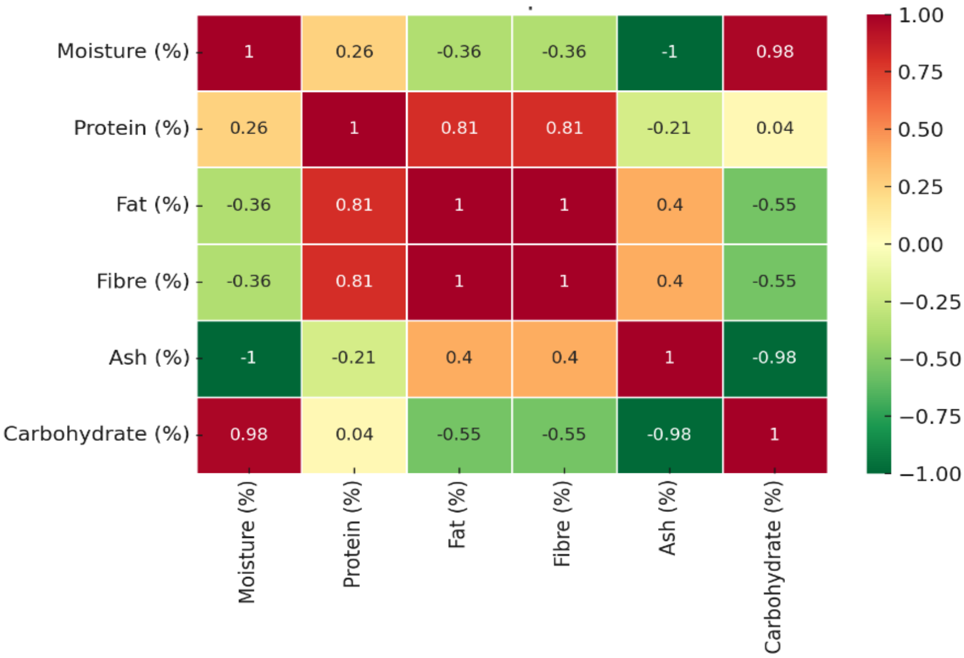

Fig. 1. Heatmap with correlation coefficients of nutritional traits in F_3 generation of red sorghum genotypes

storage properties (Adebo and Kesa 2023). In contrast, moisture and ash showed a perfect negative correlation (r = -1.00), highlighting a complete inverse relationship, where an increase in moisture leads to a corresponding decrease in ash content. This finding indicated a trade-off between water content and mineral concentration, as ash content typically represents the mineral fraction in grains. Therefore, breeding for higher moisture content might inadvertently reduce mineral density. Additionally, carbohydrate content was negatively correlated with ash (r = -0.98), fat (r = -0.55), and fibre (r = -0.55), implying that high carbohydrate levels are associated with lower proportions of these traits. This trade-off suggested that enhancing carbohydrate concentration may come at the expense of reducing fat, fibre, and mineral content, which is consistent with observations by (Adebo and Kesa 2023), where bran fractions (higher in fibre and minerals) had lower carbohydrate contents than refined flours. The heatmap presented the correlation matrix for various nutritional components in the F_4 generation, including moisture, protein, fat, fibre, ash, and carbohydrate content (**Fig. 2**). Strong positive correlations were seen between protein and fat (0.90), protein and carbohydrate (0.90), and fat and carbohydrate (1.00), indicating that as one of these components increases, the others are likely to increase as well (Rhodes *et al.,* 2017). A very strong negative correlation existed between fibre and ash (-0.99), suggesting a trade-off between these two components. Similarly, fat is negatively correlated with ash (-0.76) and moisture (-0.12), implying that higher fat content is associated with lower ash and moisture levels. Moisture positively correlated with ash (r = 0.74) but negatively with fibre (r = -0.63), supporting earlier findings that moisture content could affect the overall nutrient density of cereal grains (Adebo and Kesa 2023). These patterns could help in selecting breeding lines with optimal nutrient profiles, particularly when aiming to enhance protein and carbohydrate levels while managing moisture and fibre content (Gebre *et al.,* 2024).

This PCA-based analysis highlighted the nutritional variability among red sorghum genotypes across F_3 and F_4 generations (**Table 2**). The eigenvalue data revealed that the first principal component (PC1) explains 72.28% of the total variance, while the second component (PC2) adds an additional 23.28%. Together, PC1 and PC2 capture 95.56% of the total variability in the dataset, indicating that these two dimensions effectively summarize the multivariate data with minimal information loss (Gebre *et al.,* 2024, Rhodes *et al.,* 2017). In the biplot, ash (%) showed the longest vector along the PC1 axis, indicating it is the most influential trait contributing to variability along this component. This made ash a key factor in differentiating the lines. Carbohydrate (%), on the other hand, contributed most prominently to PC2, suggesting that it captured variability not explained by ash and other traits along PC1. Fat (%), Protein (%), and Moisture (%) were clustered closely together, showing similar directional vectors and confirming strong positive correlations among them. This implied that these traits often increase or decrease together and may be co-selected in breeding programs (Gebre *et al.,* 2024). Interestingly, fibre (%) was positioned nearly opposite to ash (%), reinforcing a strong negative correlation, consistent with the findings from the correlation heatmap. This indicated that increasing fibre content may lead to a

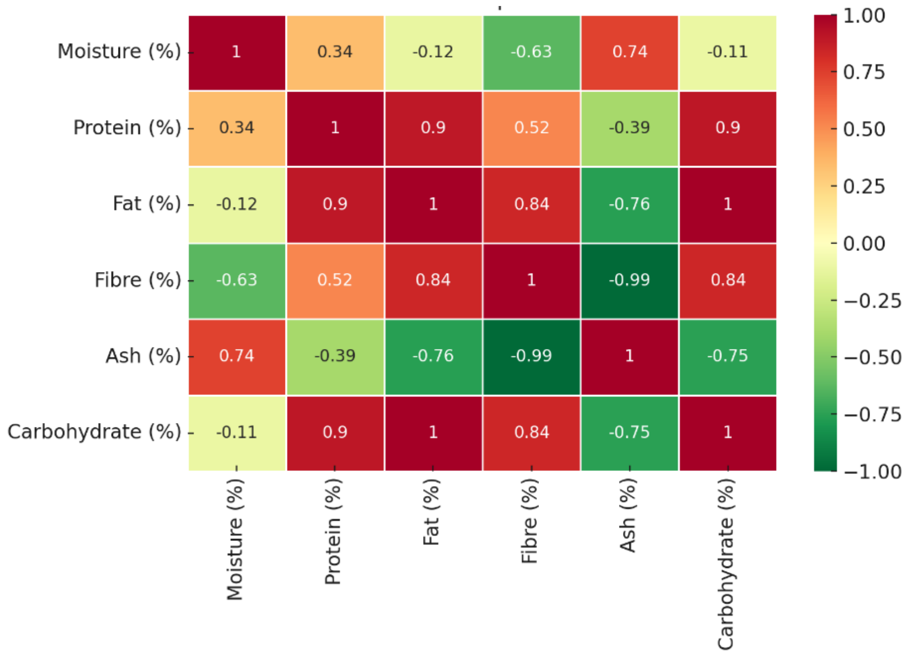

Fig. 2. Heatmap with correlation coefficient of nutritional traits in F_4 generation of red sorghum genotypes

https://doi.org/10.37992/2025.1603.032

Table 2. Principal component analysis eigenvalues and variance explained for nutritional traits in red sorghum genotypes

Component	Eigenvalue	Proportion of Variance (%)	Cumulative Proportion (%)
PC1	4.34	72.28	72.28
PC2	1.40	23.28	95.56
PC3	0.17	2.83	98.39
PC4	0.08	1.33	99.72
PC5	0.01	0.22	99.94
PC6	0.00	0.06	100.00

reduction in ash, which must be considered during trait selection to avoid unintended trade-offs (Rhodes *et al.,* 2017). The diminishing contribution of PC3 to PC6 (each explaining less than 3% of variance) confirmed their limited importance, validating the focus on PC1 and PC2 for interpretation. Overall, this PCA clearly identified ash and carbohydrate as major discriminating traits, while clustering of fat, protein, and moisture reflected their interdependence. These insights could guide breeders in prioritizing traits that maximize nutritional quality while managing trait trade-offs efficiently (Adebo and Kesa 2023, Gebre *et al.,* 2024).

This study demonstrated clear genetic advancement in the nutritional composition of red sorghum across F_3 and F_4 generations in three distinct crosses. Cross 2 (Paiyur 2 × IS 21731) showed the most promising improvement, with the highest protein (11.45%) and fat (5.66%) contents recorded in the F_4 generation. This indicated significant transgressive segregation and potential for nutritional enhancement. The expansion of trait ranges and controlled standard deviations in F_4 suggested increased genetic variability with retained stability, offering a strong base for effective selection. Correlation analysis revealed strong positive associations among protein, fat, and carbohydrate contents, while ash content showed strong negative correlations with both moisture and fibre. These findings highlighted potential trade-offs among traits, necessitating a balanced approach in breeding strategies. The PCA results confirmed that over 95% of total trait variability was captured by the first two principal components, with Ash and Carbohydrate (%) emerging as the most influential traits. Fat, protein, and moisture clustered closely, further supporting their interdependence. In summary, Cross 2 stood out for high nutritional potential, while Crosses 1 and 3 offered greater stability. The integrated statistical approach provided a comprehensive basis for selecting

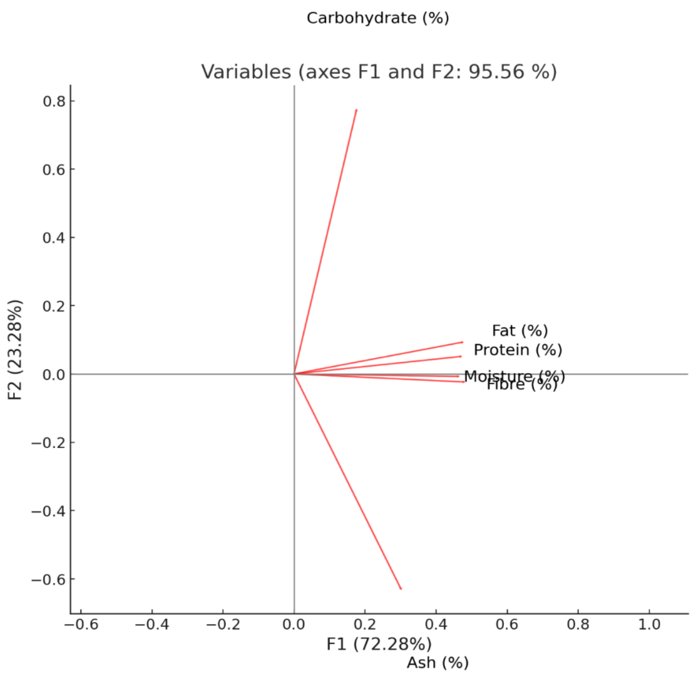

Fig. 3. Biplot of PC1 and PC2 for nutritional traits in red sorghum genotypes

elite lines with optimal nutritional profiles in red sorghum improvement programs. Future breeding efforts should integrate molecular markers to accelerate selection for nutrient-dense sorghum, especially for biofortification and climate-resilient cropping systems.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Tamil Nadu Agricultural University (TNAU) for providing support and facilitating essential logistics throughout the course of this research. Special thanks are extended to the faculty members, technical staff, and supporting personnel for their valuable assistance in data collection, analysis, and overall guidance that significantly contributed to the successful completion of this study.

REFERENCES

Abah, C. R., Ishiwu, C. N., Obiegbuna, J. E. and Oladejo, A. A. 2020. Sorghum grains: Nutritional composition, functional properties and its food applications. *European Journal of Nutrition & Food Safety*, **12**(5): 101–111. [Cross Ref]

Adebo, J. A. and Kesa, H. 2023. Evaluation of nutritional and functional properties of anatomical parts of two sorghum (*Sorghum bicolor*) varieties. *Heliyon*, **9**(6): e17747. [Cross Ref]

Andiku, C., Shimelis, H., Shayanowako, A. I. T., Gangashetty, P. I. and Manyasa, E. 2022. Genetic diversity analysis of East African sorghum (*Sorghum bicolor* [L.] Moench) germplasm collections for agronomic and nutritional quality traits. *Heliyon*, **8**(6): e09527. [Cross Ref]

Awika, J. M., Rooney, L. W. and Waniska, R. D. 2005. Anthocyanins from black sorghum and their antioxidant properties. *Food Chemistry*, **90**(1–2): 293–301. [Cross Ref]

Edeoga, H. O. and Gomina, A. 2001. Nutritional values of some non-conventional leafy vegetables of Nigeria, Scientific publishers, India. Pp 439-447.

Falmata, A. S., Modu, S., Zainab, M. A., Bintu, B. P. and Yagana, S. 2013. The soaking and dehulling effects on chemical composition, tannins and mineral elements content of five local varieties of sorghum. *Scholars Journal of Agricultural Science*, **3** (3): 126–131.

Gebre, W., Mekbib, F., Tirfessa, A. and Bekele, A. 2024. Genetic variability among lowland sorghum accessions collected from southern Ethiopia for grain quality traits. *Heliyon*, **10**(4): e26297. [Cross Ref]

Henley, E. C., Taylor, J. R. N. and Obukosia, S. D. 2010. The importance of dietary protein in human health: Combating protein deficiency in sub-Saharan Africa through transgenic biofortified sorghum. *Advances in Food and Nutrition Research,* **60**(1): 21-52. [Cross Ref]

Ihekoronye, A. I. and Ngoddy, P. O. 1985. *Integrated food science and technology for the tropics*. Macmillan.

Jimoh, W. L. O. and Abdullahi, M. S. 2017. Proximate analysis of selected sorghum cultivars. *Bayero Journal of Pure and Applied Sciences*, **10**(1): 285–288. [Cross Ref]

Kurmi, A., Jayswal, D. K., Saikia, D. and Lal, N. 2023. Current perspective on malnutrition and human health. *Nano-Biofortification for Human and Environmental Health,* Springer publication. Pp 155-177. [Cross Ref]

Manonmani, S., Suresh, M. and Khan, AKF. 2002. Genetic variability and correlation studies in red grain sorghum hybrids under rainfed condition.*Madras Agricultural Journal,* **89**(1):85-88. [Cross Ref]

Mohod, N. B., Ashoka, P., Borah, A., Goswami, P., Koshariya, A. K., Sahoo, S. and Prabhavathi, N. 2023. The international year of millet 2023: A global initiative for sustainable food security and nutrition. *International Journal of Plant & Soil Science*, **35**(19): 1204–1211. [Cross Ref]

Nayak, T., Chandirakala, R., Kavithamani, D., Manikanda Boopathi, N. and Chandrakumar, K. 2023. Unravelling genetic variability and trait association studies in red sorghum (*Sorghum bicolor* L. Moench) genotypes. *Electronic Journal of Plant Breeding,* **14**(3):1111-1117. [Cross Ref]

Ndondo, J. T. K. 2023. Review of the Food and Agriculture Organisation (FAO) strategic priorities on food safety. *Food Safety—New Insights*. IntechOpen.

Nirosh, Papineni, V.,Yuvaraja, A., Thangaraj, K. and Menaka, C. 2021. Genetic variability and association studies in segregating generation of red sorghum (*Sorghum bicolor* (L.) Moench) population. *Electronic Journal of Plant Breeding,* **12** (2):521-524. [Cross Ref]

Rhodes, D. H., Hoffmann, L., Rooney, W. L., Herald, T. J., Bean, S., Boyles, R., Brenton, Z. W. and Kresovich, S. 2017. Genetic architecture of kernel composition in global sorghum germplasm. *BMC Genomics*, **18**(1): 15-16. [Cross Ref]

Sadasivam, S. 1996. *Biochemical methods*. New Age International.

Xiong, Y., Zhang, P., Warner, R. D. and Fang, Z. 2019. Sorghum grain: From genotype, nutrition, and phenolic profile to its health benefits and food applications. *Comprehensive Reviews in Food Science and Food Safety*, **18**(6): 2025–2046. [Cross Ref]