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Qualitative Morphological Characterisation and Assessment of Genetic Diversity among Indigenous Landraces of Rice (*Oryza sativa* L.)

Vikash Sharma [a], Yogendra Singh [a*], S. K. Singh [a], Stuti Sharma [a], Kanchan Bhan [a] and Chandrabhan Ahirwar [a]

[a] Department of Genetics & Plant Breeding, College of Agriculture, JNKVV, Jabalpur- 482004, Madhya Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

The present study evaluated morphological diversity among 254 rice accessions, comprising 250 indigenous landraces and four checks (IR 64, JR 206, Improved Jeerashankar, and Improved Chinnor), using qualitative DUS descriptors and the Shannon-Weaver Diversity Index (SWDI). The study aimed to identify variable traits that could support varietal documentation, germplasm characterisation, and use in rice breeding programmes. The accessions showed substantial variation in several reproductive, panicle, awn, pigmentation, and grain-related traits, whereas some vegetative traits were conserved. Leaf collar and ligule presence were monomorphic, with 100% occurrence and no diversity (SWDI = 0.00). Leaf auricle and anthocyanin pigmentation of the nodes and internodes also showed limited variation. The highest diversity was recorded

*Corresponding author: Email: yogendrasinghbt@gmail.com;

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for panicle length of the longest awn (SWDI = 1.55), followed by awn colour (SWDI = 1.43), spikelet colour of the lemma tip (SWDI = 1.41), lemma and palea colour (SWDI = 1.40), and flag-leaf attitude at late observation (SWDI = 1.32). Panicle branch attitude was also variable, with semi-erect (40.94%), erect (30.70%), and erect-to-semi-erect (17.32%) types predominating. Moderate diversity was observed for culm attitude, spikelet pubescence, stigma colour, panicle exertion, sterile lemma colour, and secondary branching intensity. Overall, SWDI values ranged from 0.00 to 1.55. The highly variable qualitative descriptors identified in this study may support genotype identification, DUS characterisation, germplasm conservation, and the selection of diverse parental material for rice improvement programmes.

Keywords: DUS descriptors; germplasm characterisation; Shannon-weaver diversity index; qualitative traits; rice landraces.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops worldwide and provides food for more than half of the global population, particularly in Asian countries where it is a major dietary component (Fukagawa & Ziska, 2019; Muthayya *et al.*, 2014). India is a leading rice-producing country and possesses considerable genetic diversity in traditional landraces cultivated across diverse agroclimatic conditions (Wing *et al.*, 2018). Rice belongs to the family Poaceae and is a diploid species with 2n = 24 chromosomes (Juliano, 1985). India also occupies a major position in global rice cultivation as the second-largest producer and consumer. For 2025-26, USDA data indicate a harvested area of approximately 52.8 million hectares and production of about 154 million tonnes on a milled basis in India (USDA, 2025). Farmers' rice landraces are valuable genetic resources with traits related to adaptation, grain quality, stress tolerance, and yield potential. These traditional varieties have been maintained by farming communities for generations and provide variability for rice improvement programmes (Anandan *et al.*, 2011; Garris *et al.*, 2005; Singh *et al.*, 2013; Panda *et al.*, 2021). Their conservation and characterisation are important for broadening the genetic base and developing climate-resilient cultivars (Seck *et al.*, 2012). Studies of genetic variability, heritability, trait relationships, and quality attributes further support the identification of useful breeding material (Bakode *et al.*, 2025; Parmar *et al.*, 2025; Zhang *et al.*, 2011). Morphological characterisation is a practical approach for evaluating variability among rice genotypes and contributes to varietal identification and crop improvement (Chakravorty, 2024). The Distinctness, Uniformity, and Stability (DUS) testing system provides standardised descriptors for characterising plant varieties under the Protection of Plant Varieties and Farmers' Rights Act, 2001. DUS characterisation supports the identification of distinct and stable traits and assists varietal registration and protection (Borah *et al.*, 2016; Roy & Sharma, 2014).

Recent studies have shown that agro-morphological and DUS descriptors can reveal useful variation among rice landraces and support varietal differentiation, conservation, and parent selection (Prasanna *et al.*, 2024; Bordoloi *et al.*, 2024; Sar *et al.*, 2024; Sen *et al.*, 2026). Complementary molecular evidence further indicates that indigenous rice germplasm can retain substantial genetic diversity relevant to breeding and conservation (Nandedkar *et al.*, 2025).

In the present investigation, 250 farmers' rice landraces and four check varieties (IR 64, JR 206, Improved Jeerashankar, and Improved Chinnor) were evaluated using an Augmented Complete Block Design. The augmented design is suitable for evaluating a large number of genotypes when seed quantity is limited and test entries are unreplicated (Federer, 1956). Thirty morphological traits were recorded in accordance with the DUS guidelines for rice developed by the Protection of Plant Varieties and Farmers' Rights Authority, Government of India (PPV&FRA, 2007). These traits included descriptors related to plant, leaf, panicle, and grain characteristics.

Although several studies have characterised rice germplasm using qualitative DUS descriptors, comprehensive information on the phenotypic diversity of indigenous rice landraces collected in Madhya Pradesh remains limited. Systematic characterisation of these landraces is therefore needed to support varietal identification, germplasm documentation, and their effective use in future rice breeding programmes.

The objectives of the present study were to:

1. Characterise indigenous rice landraces using qualitative DUS descriptors.
2. Assess phenotypic diversity using the Shannon-Weaver Diversity Index.
3. Identify highly variable qualitative traits useful for varietal identification, germplasm conservation, and rice improvement programmes.

2. Material and Methods

The experimental material comprised 254 rice accessions, including 250 indigenous landraces and four checks (IR 64, JR 206, Improved Jeerashankar, and Improved Chinnor), obtained from the Rice Improvement Project, Department of Genetics and Plant Breeding, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India. The landraces represented germplasm collections maintained under the institutional programme for varietal development and genetic enhancement. The field experiment was conducted at the Seed Breeding Farm, Department of Genetics and Plant Breeding, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, during kharif 2024. The experiment was laid out in an Augmented Complete Block Design (ACBD) with five blocks. Each genotype was sown in a four-row plot with a row length of 4.0 m. Spacing was maintained at 20 cm between rows and 15 cm between plants. Recommended agronomic and plant-protection measures were followed to maintain a healthy crop stand throughout the growing period.

Morphological characterisation of the landraces was conducted for 30 qualitative traits following the DUS (Distinctness, Uniformity, and Stability) guidelines prescribed by the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA, 2007), Government of India. Observations on vegetative, culm, flag-leaf, panicle, spikelet, and grain-related characteristics were recorded from five randomly selected plants of each accession. The data were analysed to determine the frequency and percentage distribution of each qualitative trait. The Shannon-Weaver Diversity Index (SWDI) was calculated for each descriptor to estimate phenotypic diversity among the rice landraces, using the following formula:

$$H = -\sum_{i=1}^{n} pi\ In(pi)$$

where p_i represents the proportion of accessions belonging to the ith phenotypic class, and n denotes the total number of phenotypic classes for a particular trait. Higher SWDI values indicate greater diversity among the accessions, whereas lower values indicate greater uniformity within the germplasm (Dickman, 1968; Shannon, 1948; Shannon & Weaver, 1949).

3. Results and Discussion

Most vegetative traits exhibited varying levels of expression among the 250 indigenous rice landraces and four checks (IR 64, JR 206, Improved Jeerashankar, and Improved Chinnor), indicating both conserved and variable morphological characteristics (Table 1). Leaf auricles were present in 98.81% of the accessions, whereas only 1.18% lacked auricles, resulting in a very low diversity index (SWDI = 0.06) and indicating near fixation of this trait. Anthocyanin colouration of the auricle showed moderate variation (SWDI = 0.59), with colourless auricles predominating (82.28%), followed by light purple (10.62%) and purple (7.08%). Leaf collar and ligule were present in all accessions (100%), showing complete monomorphism (SWDI = 0.00) and indicating that these traits were highly conserved within the germplasm. Ligule shape showed moderate variability (SWDI = 0.58), with split ligules predominating (73.62%), followed by acute ligules (26.37%). Ligule colour showed relatively low diversity (SWDI = 0.34), as white ligules were dominant (91.73%), whereas light purple and purple ligules occurred at lower frequencies. Comparable stability in collar and ligule traits was reported by Priyanga *et al.* (2020), Pachauri *et al.* (2020), and Umarani *et al.* (2017).

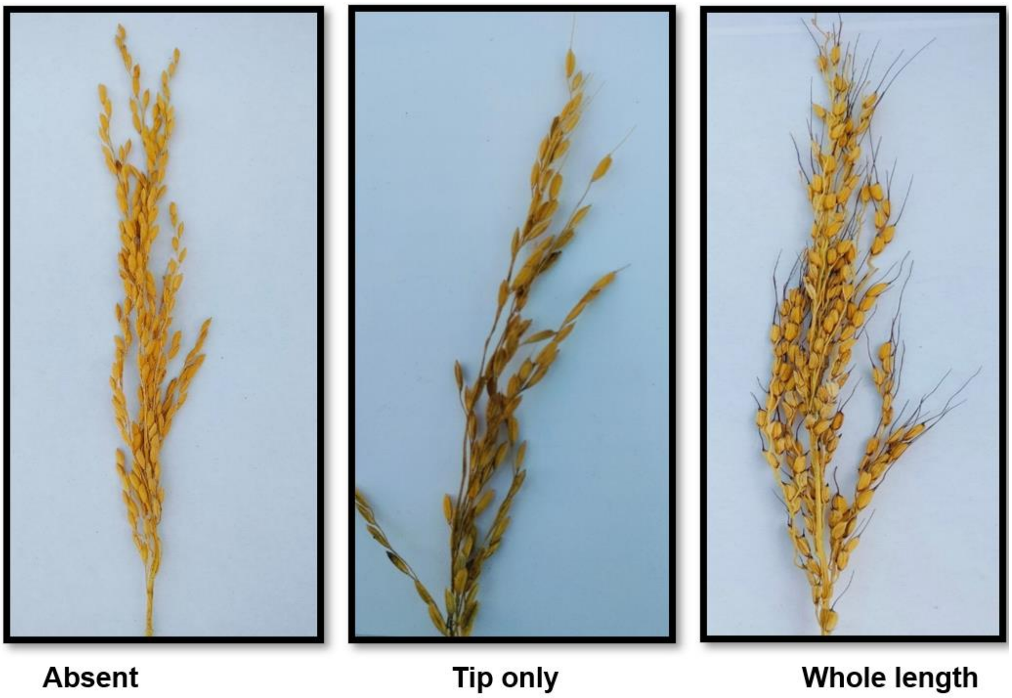
Moderate to high variation was observed in traits related to plant architecture. Culm attitude showed appreciable diversity (SWDI = 0.86), with erect (52.36%) and semi-erect (42.12%) types predominating, whereas open culms occurred less frequently (5.51%) (Fig. 1).

Flag-leaf attitude at the early stage also showed moderate variability (SWDI = 0.89), with erect (51.96%) and semi-erect (40.94%) categories predominating and a small proportion showing a horizontal orientation (7.08%).

At the late observation, diversity increased (SWDI = 1.32), with erect (41.73%), semi-erect (28.74%), horizontal (16.92%), and deflexed (12.59%) orientations. Similar variability in culm attitude and flag-leaf orientation was documented by Mondal *et al.* (2014) and Kumbhar *et al.* (2015), who identified these descriptors as useful for varietal distinctiveness and adaptation in rice germplasm.

Erect **Semi-Erect** **Open**

Fig. 1. Variation in Culm: attitude



Absent **Tip only** **Whole length**

Fig. 2. Panicle distributions of awns

Table 1. Frequency distribution of morphological traits in the indigenous rice landraces

S.no.	Traits	Stages	Expression	No. of accession	Frequency (%)	SWDI
1	Leaf: auricle	Booting	Present	251	98.81	0.06
			Absent	3	1.18	
2	Leaf: anthocyanin colouration of auricle	Booting	Colour less	209	82.28	0.59
			Light purple	27	10.62	
			Purple	18	7.08	
3	Leaf: collar	Booting	Absent	0	0.00	0.00
			Present	254	100.00	
4	Leaf: anthocyanin colouration of collar	Booting	Absent	226	88.97	0.35
			Present	28	11.02	
5	Leaf: ligule	Booting	Absent	0	0.00	0.00
			Present	254	100.00	
6	Leaf: shape of ligule	Booting	Truncate	0	0.00	0.58
			Acute	67	26.37	
			Split	187	73.62	
7	Leaf: colour of ligule	Booting	White	233	91.73	0.34
			Light purple	14	5.51	
			Purple	7	2.75	
8	Culm: attitude	Booting	Erect	133	52.36	0.86
			Semi-erect	107	42.12	
			Open	14	5.51	
9	Flag leaf: attitude of blade (early)	Beginning of anthesis	Erect	132	51.96	0.89
			Semi-erect	104	40.94	
			Horizontal	18	7.08	
			Drooping	0	0.00	
10	Spikelet: density of pubescence of lemma	Spikelets become hard	Absent	11	4.33	1.28
			Weak	42	16.53	
			Medium	97	38.18	
			Strong	71	27.95	
			Very strong	11	4.33	
11	Lemma: anthocyanin colouration of Keel	Anthesis half way	Absent	159	62.59	0.92
			Weak	28	11.02	
			Medium	56	22.04	

S.no.	Traits	Stages	Expression	No. of accession	Frequency (%)	SWDI
			Strong	11	4.33	
			Very strong	0	0.00	
12	Lemma: anthocyanin colouration of area below apex	Anthesis half way	Absent	167	65.74	0.85
			Weak	29	11.41	
			Medium	49	19.29	
			Strong	9	3.54	
			Very strong	0	0.00	
13	Lemma: anthocyanin colouration of apex	Anthesis half way	Absent	167	65.74	0.84
			Weak	29	11.41	
			Medium	58	22.83	
			Strong	0	0.00	
			Very strong	0	0.00	
14	Spikelet: colour of stigma	Anthesis half way	White	148	58.36	0.92
			Light green	0	0.00	
			Yellow	29	11.41	
			Light purple	0	0.00	
			Purple	77	30.31	
15	Stem: anthocyanin colouration of nodes	Milk development stage	Absent	231	90.94	0.30
			Present	23	9.05	
16	Stem: intensity of anthocyanin colouration of nodes	Milk development stage	Weak	3	1.18	0.99
			Medium	11	4.33	
			Strong	9	3.54	
17	Stem: anthocyanin colouration of internodes	Milk development stage	Absent	225	88.58	0.36
			Present	29	11.41	
18	Flag leaf: attitude of blade (late observation)	Ripening	Erect	106	41.73	1.32
			Semi-erect	73	28.74	
			Horizontal	43	16.92	
			Deflexed	32	12.59	
19	Panicle: curvature of main axis	Ripening	Straight	19	7.48	1.22
			Semi -straight	89	35.03	
			Deflexed	97	38.18	
			Dropping	49	19.29	
20	Spikelet: colour of tip of lemma	Ripening	White	113	44.48	1.41
			Yellowish	21	8.26	

S.no.	Traits	Stages	Expression	No. of accession	Frequency (%)	SWDI
			Brown	74	29.13	
			Red	9	3.54	
			Purple	28	11.02	
			Black	9	3.54	
21	Lemma and palea: colour	Dough-Ripening	Straw	143	56.19	1.40
			Gold and gold furrows on straw background	32	12.59	
			Brown spots on straw	11	4.33	
			Brown furrows on straw	25	9.84	
			Brown (tawny)	24	9.44	
			Purple spots/furrows on straw	0	0.00	
			Purple	11	4.33	
			Black	8	3.14	
22	Panicle: awns	Ripening	Absent	201	79.13	0.51
			Present	53	20.86	
23	Panicle: colour of awns (late)	Ripening	Absent	23	9.05	1.43
			Yellowish white	0	0.00	
			Yellowish brown	3	1.18	
			Brown	8	3.14	
			Reddish brown	9	3.54	
			Light red	0	0.00	
			Red	2	0.78	
			Light purple	5	1.96	
			Purple	2	0.78	
			Black	1	0.39	
24	Panicle: distribution of awns	Ripening	Tip only	14	5.51	0.65
			Upper half only	18	7.08	
			Whole length	21	8.26	
			Absent	201	79.13	
25	Panicle: Presence of secondary branching	Ripening	Present	247	97.24	0.13
			Absent	7	2.75	

S.no.	Traits	Stages	Expression	No. of accession	Frequency (%)	SWDI
26	Panicle: secondary branching	Ripening	Weak	74	29.13	0.69
			Strong	175	68.89	
			Clustered	5	1.96	
27	Panicle: attitude of branches	Ripening	Erect	78	30.70	1.28
			Erect to semi-erect	44	17.32	
			Semi-erect	104	40.94	
			Semi-erect to Spreading	19	7.48	
			Spreading	9	3.54	
28	Panicle: exertion	Ripening	Partially exerted	43	16.92	1.03
			Mostly exerted	114	44.88	
			Well exerted	97	38.18	
29	Sterile lemma colour	Caryopsis hard	Gold	25	9.84	0.75
			Straw	193	75.98	
			Red	7	2.75	
			Purple	29	11.41	
30	Panicle Length of the longest awn	Ripening	Very short	9	3.54	1.55
			Short	6	2.30	
			Medium	16	6.29	
			Long	15	5.90	
			Very long	13	5.11	

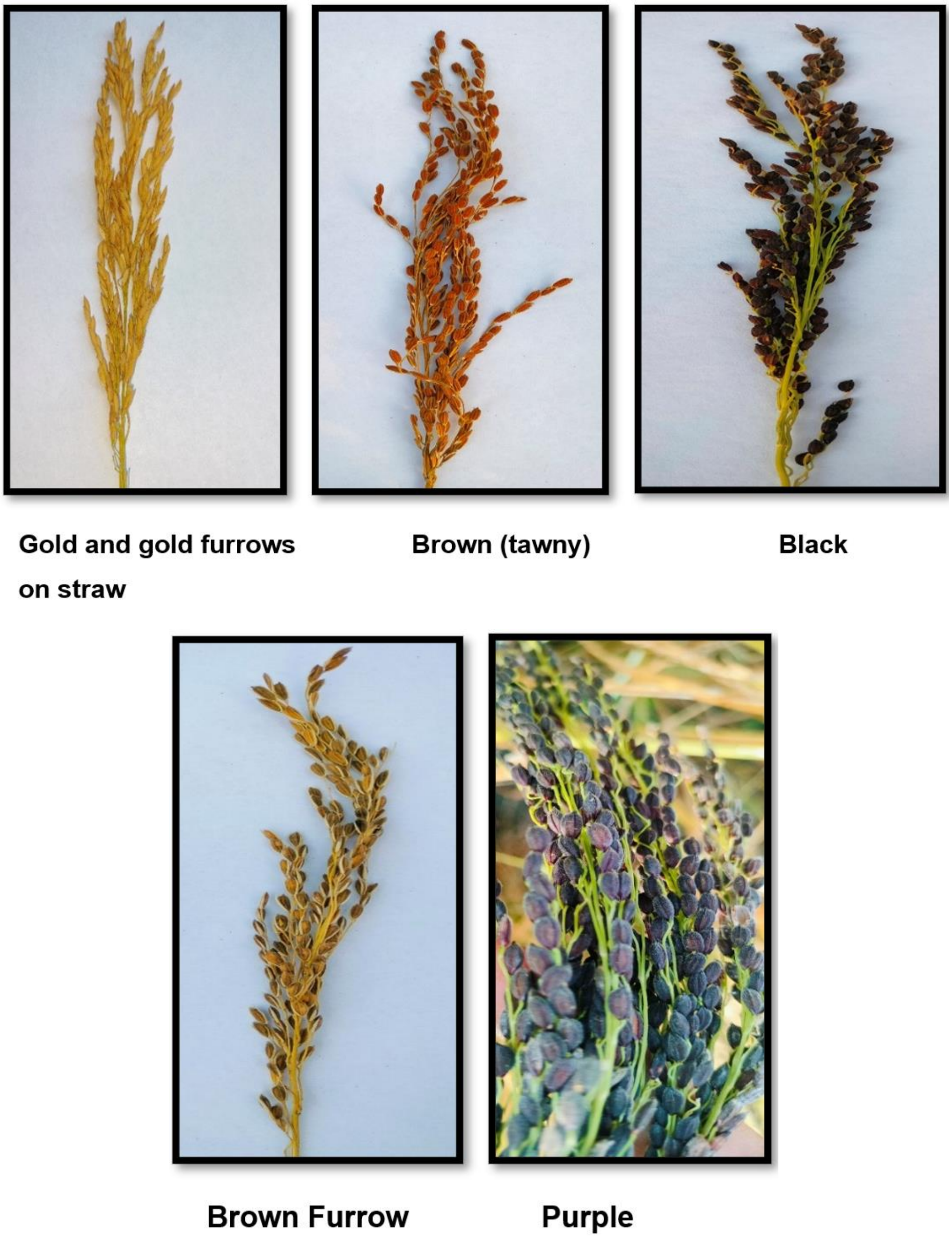


Fig. 3. Lemma and palea colour variation

Anthocyanin pigmentation and spikelet-related descriptors showed different levels of variability among the accessions. Anthocyanin colouration of the collar, nodes, and internodes showed relatively low diversity, with pigmentation absent in most accessions and SWDI values ranging from 0.30 to 0.36. However, the intensity of anthocyanin colouration in the nodes of pigmented accessions showed greater diversity (SWDI = 0.99), including weak (1.18%), medium (4.33%), and strong (3.54%) classes. Spikelet pubescence of the lemma showed substantial variation (SWDI = 1.28), with medium pubescence (38.18%) predominating, followed by strong (27.95%), weak (16.53%), and very strong or absent classes. Anthocyanin pigmentation of the lemma keel, apex, and area below the apex showed moderate variability, with SWDI values ranging from 0.84 to 0.92, although non-pigmented spikelets predominated. Stigma colour showed moderate diversity (SWDI = 0.92), with white stigmas predominating (58.36%), followed by purple (30.31%) and yellow (11.41%). Similar variability in pigmentation and pubescence traits was reported by Rawte and Saxena (2018), Priyanga *et al.* (2020), and

Kalagare *et al.* (2018), who recognised these descriptors as useful markers for genotype identification and DUS characterisation.

Panicle-related descriptors showed the highest phenotypic variability among the qualitative traits studied. Panicle curvature of the main axis showed considerable diversity (SWDI = 1.22), with deflexed (38.18%) and semi-straight (35.03%) types predominating, followed by dropping (19.29%) and straight (7.48%) forms. Panicle branch attitude was also highly variable (SWDI = 1.28), comprising semi-erect (40.94%), erect (30.70%), erect-to-semi-erect (17.32%), semi-erect-to-spreading (7.48%), and spreading (3.54%) types. Panicle exertion showed moderate diversity (SWDI = 1.03), with mostly exerted (44.88%) and well-exerted (38.18%) panicles predominating. Secondary branching was nearly fixed (97.24% present), although branching intensity varied (SWDI = 0.69), with strong branching (68.89%) being the most common. These findings agree with those of Priyanga *et al.* (2020), Kalyan *et al.* (2017), and Manjunatha *et al.* (2018), who identified panicle morphology as a major contributor to varietal differentiation and agro-morphological diversity in rice.

Awn- and grain-associated descriptors showed both uniformity and high diversity, depending on the characteristic examined. Panicle awns were absent in 79.13% of the accessions, resulting in relatively low diversity (SWDI = 0.51), whereas awn colour among the awned genotypes showed substantial variability (SWDI = 1.43), including brown, reddish-brown, purple, black, and related colour classes (Fig. 4). Awn distribution showed moderate variation (SWDI = 0.65), whereas the length of the longest awn recorded the highest diversity index among all traits studied (SWDI = 1.55). Spikelet colour at the lemma tip showed high diversity (SWDI = 1.41), with white (44.48%) and brown (29.13%) predominating, together with yellowish, purple, red, and black classes. Lemma and palea colour also showed substantial diversity (SWDI = 1.40), with straw colour predominating (56.19%) and gold, brown, purple, and black forms also present. Sterile lemma colour showed moderate diversity (SWDI = 0.75), with straw colour predominating (75.98%) (Fig. 3). Similar variability in awn and grain-colour traits has been documented by Demeke *et al.* (2023), Mazid *et al.* (2013), Kalagare *et al.* (2018), and Kumbhar *et al.* (2015), supporting their use in DUS characterisation and germplasm discrimination. Morphological characterisation of rice landraces is important for crop improvement programmes (Gautam *et al.*, 2024; Ahirwar *et al.*, 2026). Overall, the Shannon-Weaver Diversity Index showed substantial qualitative diversity among the indigenous rice landraces, particularly for panicle morphology, awn characteristics, and grain-associated traits. Collar and ligule presence remained highly conserved, whereas panicle architecture and pigmentation descriptors showed broader variation, indicating their potential value for genotype identification, conservation, and use in rice improvement programmes.

Yellowish white **Brown**

Fig. 4. Variation in Panicle coloration of Awns

4. Conclusions

Morphological characterisation of the 254 rice accessions revealed clear differences in the distribution and diversity of qualitative DUS descriptors. Leaf collar and ligule presence were highly conserved, whereas traits associated with the panicle, awns, pigmentation, and grain contributed most strongly to phenotypic differentiation. The length of the longest awn recorded the highest Shannon–Weaver Diversity Index, followed by awn colour, lemma-tip colour, lemma and palea colour, and flag-leaf attitude at late observation. Culm attitude, spikelet pubescence, stigma colour, panicle exertion, sterile lemma colour, and secondary branching intensity showed moderate diversity. These findings identify a set of qualitative descriptors that can support varietal identification, germplasm documentation, and DUS-based characterisation of indigenous rice materials. The observed variation may also help breeders select phenotypically distinct parental lines while maintaining landrace resources for future use. Because the assessment was based on qualitative morphology, the results should be interpreted as evidence of phenotypic diversity. Multi-environment evaluation of quantitative traits and complementary molecular analysis would provide a more complete understanding of relationships among the evaluated accessions.

5. Limitations

The study assessed qualitative morphological descriptors during one crop season at a single location. Consequently, environmental effects on trait expression could not be separated from stable genotypic differences. The Shannon–Weaver Diversity Index summarised phenotypic class distribution but did not quantify molecular diversity or genetic relationships among accessions. Quantitative agronomic traits were also outside the present assessment. Multi-season and multi-location evaluation, together with molecular marker analysis, would be required to confirm the stability of the observed diversity patterns and to support more comprehensive selection decisions.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data generation, content development, interpretation of results, and related scholarly work. The author(s) acknowledge using Grammarly and ChatGPT to assist with grammar checking, language refinement, and reference formatting. These AI-assisted tools were not listed as authors and did not replace the intellectual contributions or scholarly judgement of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

References

Ahirwar, C., Singh, S. K., & Singh, Y. (2026). Morphological characterization and genetic diversity assessment in rice (*Oryza sativa* L.) genotypes using DUS descriptors. *Journal of Advances in Biology & Biotechnology, 29*(4), 319–327. https://doi.org/10.9734/jabb/2026/v29i43795

Anandan, A., Rajiv, G., Eswaran, R., & Prakash, M. (2011). Genotypic variation and relationships between quality traits and trace elements in traditional and improved rice (*Oryza sativa* L.) genotypes. *Journal of Food Science, 76*(4), H122–H130. https://doi.org/10.1111/j.1750-3841.2011.02135.x

Bakode, S., Singh, S. K., Koutu, G. K., Prajapati, S. S., Kumar, P., & Elahi, T. (2025). Analysis of genetic variability, heritability, and genetic advance in rice (*Oryza sativa* L.). *Journal of Advances in Biology & Biotechnology, 28*(11), 1557–1564. https://doi.org/10.9734/jabb/2025/v28i113341

Borah, P., Sarma, D., Dey, P. C., Chowdhury, R. K., & Hazarika, G. N. (2016). DUS characterization of rice genotypes. *ORYZA—An International Journal on Rice, 53*(4), 454–457. https://arrworyza.com/AdminPanel/download/Dus%20characterization%20of%20rice%20genotypes.pdf

Bordoloi, D., Sarma, D., Sarma Barua, N., Das, R., & Das, B. K. (2024). Morpho-molecular and nutritional profiling for yield improvement and value addition of indigenous aromatic Joha rice of Assam. *Scientific Reports, 14*, Article 3509. https://doi.org/10.1038/s41598-023-42874-9

Chakravorty, A. (2024). Assessment of rice germplasms through DUS testing guidelines. In *Advanced research in biological science* (Vol. 9, pp. 171–187). Book Publisher International. https://doi.org/10.9734/bpi/arbs/v9/8864A

Demeke, B., Dejene, T., & Abebe, D. (2023). Genetic variability, heritability, and genetic advance of morphological, yield-related, and quality traits in upland rice (*Oryza sativa* L.) genotypes at Pawe, northwestern Ethiopia. *Cogent Food & Agriculture, 9*(1), Article 2157099. https://doi.org/10.1080/23311932.2022.2157099

Dickman, M. (1968). Some indices of diversity. *Ecology, 49*(6), 1191–1193. https://doi.org/10.2307/1934512

Federer, W. T. (1956). Augmented (or Hoonuiaku) designs. *Hawaiian Planters' Record, 55*, 191–208. https://ecommons.cornell.edu/entities/publication/22e171a6-71d7-422a-9de5-9d7cc372ccd0

Fukagawa, N. K., & Ziska, L. H. (2019). Rice: Importance for global nutrition. *Journal of Nutritional Science and Vitaminology, 65*(Supplement), S2–S3. https://doi.org/10.3177/jnsv.65.S2

Garris, A. J., Tai, T. H., Coburn, J., Kresovich, S., & McCouch, S. (2005). Genetic structure and diversity in *Oryza sativa* L. *Genetics, 169*(3), 1631–1638. https://doi.org/10.1534/genetics.104.035642

Gautam, R., Singh, Y., Singh, S. K., Tiwari, S., Satpathy, S., & Pani, D. R. (2024). Quality assessment and variability estimation in rice landraces. *ORYZA—An International Journal on Rice, 61*(4), 274–282. https://doi.org/10.35709/ory.2024.61.4.1

Juliano, B. O. (Ed.). (1985). *Rice: Chemistry and technology* (2nd ed.). American Association of Cereal Chemists. https://worldveg.tind.io/record/3407

Kalagare, V. S., Saxena, R. R., & Rawte, S. (2018). Morphological characterization of super core rice (*Oryza sativa* L.) germplasm using DUS description. *International Journal of Chemical Studies, 6*(3), 2465–2469. https://www.academia.edu/83654290/Morphological_characterization_of_super_core_rice_Oryza_sativa_L_germplasm_using_dus_description

Kalyan, B., Radha Krishna, K. V., & Subba Rao, L. V. (2017). DUS characterization for germplasm of rice. *International Journal of Current Microbiology and Applied Sciences, 6*(10), 3480–3487. https://doi.org/10.20546/ijcmas.2017.610.410

Kumbhar, S. D., Kulwal, P. L., Patil, J. V., Sarawate, C. D., Gaikwad, A. P., & Jadhav, A. S. (2015). Genetic diversity and population structure in landraces and improved rice varieties from India. *Rice Science, 22*(3), 99–107. https://doi.org/10.1016/j.rsci.2015.05.013

Manjunatha, G. A., Elsy, C. R., Rajendran, P., Joseph, J., Francies, R. M., & Krishnan, S. (2018). DUS characterization of rice (*Oryza sativa* L.) landraces of Wayanad, Kerala. *Electronic Journal of Plant Breeding, 9*(2), 617–630. https://doi.org/10.5958/0975-928X.2018.00076.5

Mazid, M. S., Rafii, M. Y., Hanafi, M. M., Rahim, H. A., Shabanimofrad, M., & Latif, M. A. (2013). Agro-morphological characterization and assessment of variability, heritability, genetic advance, and divergence in bacterial blight-resistant rice genotypes. *South African Journal of Botany, 86*, 15–22. https://doi.org/10.1016/j.sajb.2013.01.004

Mondal, B., Singh, S. P., & Joshi, D. C. (2014). DUS characterization of rice (*Oryza sativa* L.) using morphological descriptors and quality parameters. *Outlook on Agriculture, 43*(2), 131–137. https://www.researchgate.net/publication/263013583_DUS_Characterization_of_Rice_Oryza_Sativa_L_Using_Morphological_Descriptors_and_Quality_Parameters

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences, 1324*(1), 7–14. https://doi.org/10.1111/nyas.12540

Nandedkar, K., Saxena, R. R., Parikh, M., Sahu, P. K., Rawte, S., & Sarawgi, A. K. (2025). SSR marker-based insights into genetic diversity and population structure of rice (*Oryza sativa* L.) germplasm. *Plant Cell Biotechnology and Molecular Biology, 26*(9–10), 148–161. https://doi.org/10.56557/pcbmb/2025/v26i9-109739

Pachauri, A. K., Sarawgi, A. K., Bhandarkar, S., & Nair, S. K. (2020). Characterization and variability analysis of rice germplasm accessions for morphological traits. *Journal of Pharmacognosy and Phytochemistry, 9*(5), 1407–1413. https://www.phytojournal.com/archives/2020/vol9issue5/PartT/9-5-193-736.pdf

Panda, D., Mishra, S. S., & Behera, P. K. (2021). Drought tolerance in rice: Focus on recent mechanisms and approaches. *Rice Science, 28*(2), 119–132. https://doi.org/10.1016/j.rsci.2021.01.002

Parmar, H., Singh, Y., Singh, S. K., Sharma, S., Banerjee, J., & Sharma, V. (2025). Genetic variability, correlation, and path analysis for yield and quality-attributing traits in biofortified rice genotypes. *Journal of Experimental Agriculture International, 47*(8), 217–225. https://doi.org/10.9734/jeai/2025/v47i83664

Prasanna, G. S. S., Joshi, J. L., & Muraleedharan, A. (2024). Distinctiveness, uniformity and stability (DUS) characterization in twenty-five landraces of rice (*Oryza sativa* L.). *Journal of Advances in Biology & Biotechnology, 27*(3), 77–84. https://doi.org/10.9734/jabb/2024/v27i3722

Priyanga, R. S., Kumaresan, D., Amudha, K., & Geetha, S. (2020). Study of morphological diversity of rice landraces (*Oryza sativa* L.). *Electronic Journal of Plant Breeding, 11*(2), 585–594. https://doi.org/10.37992/2020.1102.097

Protection of Plant Varieties and Farmers' Rights Authority. (2007). *Guidelines for the conduct of tests for distinctness, uniformity and stability on rice (Oryza sativa L.)* (PPV&FRA Test Guideline No. TG/16/2007). Government of India. https://plantauthority.gov.in/sites/default/files/grice.pdf

Rawte, S., & Saxena, R. R. (2018). Morphological characterization of selected rice (*Oryza sativa* L.) from the core germplasm group of Chhattisgarh using DUS descriptors. *International Journal of Current Microbiology and Applied Sciences, 7*(10), 350–357. https://doi.org/10.20546/ijcmas.2018.710.037

Roy, S. C., & Sharma, B. D. (2014). Assessment of genetic diversity in rice [*Oryza sativa* L.] germplasm based on agro-morphology traits and zinc–iron content for crop improvement. *Physiology and Molecular Biology of Plants, 20*, 209–224. https://doi.org/10.1007/s12298-014-0221-y

Sar, P., Gupta, S., Behera, M., Chakraborty, K., Ngangkham, U., Verma, B. C., Banerjee, A., Hanjagi, P. S., Bhaduri, D., Shil, S., Kumar, J., Mandal, N. P., Kole, P. C., Purugganan, M. D., & Roy, S. (2024). Exploring genetic diversity within aus rice germplasm: Insights into variations in agro-morphological traits. *Rice, 17*, Article 20. https://doi.org/10.1186/s12284-024-00700-4

Seck, P. A., Diagne, A., Mohanty, S., & Wopereis, M. C. S. (2012). Crops that feed the world 7: Rice. *Food Security, 4*, 7–24. https://doi.org/10.1007/s12571-012-0168-1

Sen, A., Yasmin, F., Sarkar, M. J., Rahman, M. O., Singh, A. S. H., & Rahman, M. A. (2026). Genetic and morphological trait diversity in Aman rice germplasm (*Oryza sativa* L.). *Discover Plants, 3*, Article 43. https://doi.org/10.1007/s44372-026-00503-5

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal, 27*(3), 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press. https://www.press.uillinois.edu/books/?id=p725487

Singh, N., Choudhury, D. R., Singh, A. K., Kumar, S., Srinivasan, K., Tyagi, R. K., Singh, N. K., & Singh, R. (2013). Comparison of SSR and SNP markers in estimation of genetic diversity and population structure of Indian rice varieties. *PLOS ONE, 8*(12), e84136. https://doi.org/10.1371/journal.pone.0084136

Umarani, E., Radhika, K., Padma, V., & Subbarao, L. V. (2017). Agro-morphological characterization of rice (*Oryza sativa* L.) landraces based on DUS descriptors. *International Journal of Pure & Applied Bioscience, 5*(4), 466–475. https://doi.org/10.18782/2320-7051.2624

United States Department of Agriculture, Foreign Agricultural Service. (2025). *Production, supply and distribution online database: Rice statistics for India* [Data set]. https://apps.fas.usda.gov/psdonline/

Wing, R. A., Purugganan, M. D., & Zhang, Q. (2018). The rice genome revolution: From an ancient grain to Green Super Rice. *Nature Reviews Genetics, 19*, 505–517. https://doi.org/10.1038/s41576-018-0024-z

Zhang, P., Li, J., Li, X., Liu, X., Zhao, X., & Lu, Y. (2011). Population structure and genetic diversity in a rice core collection (*Oryza sativa* L.) investigated with SSR markers. *PLOS ONE, 6*(12), e27565. https://doi.org/10.1371/journal.pone.0027565

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