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Dus characterization of grain amaranth (*Amaranthus hypochondriacus* L.) for qualitative traits

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Abstract

The present study was conducted at All India Coordinated Research Network on Potential Crops ICAR, NBPGR, New Delhi, RMD CARS Ajirma, Ambikapur (Chhattisgarh), during the *Rabi* 2024 season. The experiment was carried out to perform Distinctness, Uniformity and Stability (DUS) characterization of grain amaranth genotypes with the objective of characterizing and evaluating diverse grain amaranth germplasm using standard DUS descriptors. The trial was laid out in a Randomized Block Design (RBD) with three replications and both qualitative and quantitative traits were assessed in twenty-one amaranth genotypes. All genotypes exhibited variation for almost all qualitative traits including leaf blade blotch (absent and present), leaf blade main colour (green and purple), inflorescence colour (yellowish green and pink), inflorescence compactness (lax, intermediate and dense), inflorescence spininess (absent and present), inflorescence shape (globose, semi-drooping and straight), stem colour (yellowish green and pink), stem surface (smooth and ridged) and seed colour (creamish, pale yellow and golden). DUS descriptor-based characterization revealed considerable variation among genotypes for qualitative traits such as leaf blotch (9.5% present), leaf blade colour (33% purple) and inflorescence colour (33% pink).

Keywords: Distinctness, uniformity, qualitative traits and quantitative traits

Introduction

Grain amaranth (*Amaranthus hypochondriacus* L.) is among the earliest domesticated food crops of the New World and continues to hold considerable importance in both traditional and modern agricultural systems across several regions. As one of the three major pseudocereals, along with buckwheat (*Fagopyrum* spp.) and chenopods (*Chenopodium* spp.) amaranth is distinguished by its superior nutritional quality and wide adaptability (Janssen *et al.*, 2017) [6]. The term “amaranth” is derived from the Greek word *amarantos* meaning “unfading flower” referring to its long-lasting inflorescences. The principal centres of diversity are South and Central America, Southeast Asia and India whereas secondary centres have been reported in both East and West Africa (Rai and Yadav 2005) [14]. Morphologically amaranth is a fast-growing, erect and herbaceous annual exhibiting wide phenotypic variation. It possesses a well-developed taproot system and may attain a height of 0.3 to 2.5 m, depending on the species, environmental conditions and cultivation practices. The leaves are alternate, simple, long-petiolate and their colour varies from green to red, including several intermediate shades. In some species distinctive foliar markings are also observed. Most cultivated forms are monoecious and predominantly wind-pollinated, although grain types with brightly coloured inflorescences may attract bees (Khoshoo and Pal 1970) [8].

Amaranth follows the C₄ photosynthetic pathway, which contributes to its high photosynthetic efficiency and effective water use under conditions of elevated temperature and intense solar radiation. In India, it is commonly consumed as a leafy vegetable often in combination with potatoes and other vegetables. In Chhattisgarh, *A. tricolor* locally known as “Lal Bhaji” is widely used as a traditional vegetable and its tender shoots, petioles and leaves are regularly harvested for consumption.

Although underutilized, amaranth possesses substantial nutritional and medicinal value. Its vegetative parts are rich in moisture (85.70%), protein (4.0 g), fat (0.50 g), carbohydrates

(6.30 g), calcium (397 mg), iron (25.5 mg), phosphorus (83 mg), vitamin A (9200 IU) and vitamin C (99 mg) (Rai and Yadav 2005) ^[14]. The seeds though very small, contain 14-19% protein with a well-balanced amino acid profile particularly a high lysine content of 5-8% making them nutritionally superior to many conventional cereals (Downton 1973) ^[5]. At the global level, grain amaranth is cultivated in countries such as Mexico, Peru, Argentina, China and the United States over several hundred thousand hectares with yields ranging from 800 to 3,000 kg ha⁻¹. Its market value was estimated at USD 8.13 billion in 2024 and is projected to increase steadily due to its nutritional benefits and tolerance to climatic stress (Polaris Market Research 2025) ^[12], whereas, in India cultivation spans about 40,000 to 50,000 hectares. Mainly in Gujarat, Uttarakhand, Maharashtra and Karnataka with productivity ranging from 1,000 to 2,000 kg/ha. India has become an important exporter, especially to the U.S. and Europe (H. L. Raiger and N. K. Jagoriya 2024) ^[13]. In Chhattisgarh, grain amaranth is primarily cultivated during *Rabi* season with an estimated productivity reaching up to 2000 kg/ha in the plains (Kumar *et al.*, 2018) ^[9]. Therefore, systematic research is required to identify superior genotypes of amaranth. High-yielding genotypes are essential for improving production in suitable agro-climatic regions. In addition the development and use of quality seed are necessary to ensure better nutritional availability and yield potential. In view of these considerations, the present investigation was undertaken to morphologically characterize grain amaranth according to DUS guidelines and to evaluate yield-attributing traits.

Materials and Methods

In the present experiment, morphological characterization of grain amaranth was carried out on 21 genotypes (Table 1), collected from All India Coordinated Research Network on Potential Crops ICAR, NBPGR, New Delhi and RMD CARS Ambikapur, Chhattisgarh, with under the supervision of the Department of Genetics and Plant Breeding during the *Rabi* season of 2024-25. The study site was located at 20°8'N latitude, 83°15'E longitude and an altitude of 592.62 m above mean sea level. The experiment was laid out in a Randomized Block Design (RBD) with three replications.

Table 1: Genotypes used for the study

S.N.	Genotypes	S.N.	Genotypes	S.N.	Genotypes
1.	EC033345	8.	RMA24-62	15.	SKNA-2103
2.	IC038468	9.	AGR23-2	16.	SKNA-2105
3.	IC313250	10.	BGA-7	17.	SKNA-1902
4.	IC467913	11.	BGA-41	18.	GA-5 (check)
5.	RMA24-8	12.	BGA47-1	19.	SUVARNA (check)
6.	RMA24-17	13.	BGA-24	20.	BGA-2 (check)
7.	RMA24-43	14.	SKNA-2003	21.	RMA-7 (check)

Statistical analysis

Observations were recorded on five randomly selected plants from each genotype in each replication and the mean values were calculated following the DUS descriptors and presented in Table 2. Morphological traits of grain amaranth were recorded at different growth stages on the basis of individual plants for each genotype in accordance with the DUS guidelines of PPV and FR. The investigation was conducted during the *Rabi* season of 2024-25. All

recommended agronomic practices and plant protection measures were followed to ensure healthy crop growth.

Table 2: Qualitative parameters for recording observation in Grain amaranth. (According to DUS guidelines PPV and FFR)

S. N.	Item	Parameter
1	Leaf blade: presence of blotch	1 Absent 9 Present 99 Others
2	Leaf blade: Main colour	3 Green 7 Purple 99 Others
3	Inflorescence colour	1. Light yellow 2. Yellow 3. Yellowish green 4. Orange 5. Pink 6. Pinkish green 7. Purple 8. Red 9. Reddish green 10. Green 99 Others
4	Inflorescence compactness	3 Lax 5 Intermediate 7 Dense 99 Others
5	Inflorescence spininess	1 Absent 9 Present 99 Others
6	Inflorescence shape	1 Globose 2 Semi drooping 3 Completely drooping 4 Straight 99 Others
7	Stem colour	3 Yellowish green 5 Pink 7 Red 99 Others
8	Stem surface	1 Smooth 9 Ridged 99 Others
9	Seed colour	1. White 2. Creamish 3. Pale yellow 4. Pink 5. Red 6. Brown 7. Black 8. Golden 99 Others

Results and Discussion

Plant leaf blotch

Plant leaf blotch was present in genotypes IC313250 and RMA24-8, whereas it was absent in EC033345, IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-7, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5, SUVARNA, BGA-2 and RMA-7. The differential occurrence of leaf blotch among genotypes suggests variation in susceptibility or expression of this symptom, which may be influenced by genotype-environment

interaction or inherent genetic differences in disease response. Similar qualitative differences in leaf-spot-like symptoms among amaranth accessions have also been reported by Lagad *et al.* (2023) ^[11] in DUS-based morphological studies, indicating that such traits can be useful for preliminary screening of disease-related responses in germplasm.

Leaf blade main colour

Leaf blade main colour appeared purple in EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105 and GA-5 while IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, SUVARNA, BGA-2 and RMA-7 exhibited green leaf blades. Kamini and Yadav (2023) ^[7] described purple, reddish-green and green leaf colours as stable descriptors in grain amaranth germplasm. This clear dichotomy in leaf colour reflects genetic polymorphism for anthocyanin pigmentation, consistent with their reports on qualitative colour variation.

Inflorescence colour

Inflorescence colour was recorded as pink in EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, GA-5 and RMA-7 whereas IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, SUVARNA and RMA-7 showed yellowish-green inflorescences. Similar observations were also reported by Chatarmal and Kute (2013) in grain *Amaranthus*.

Inflorescence spininess

Inflorescence spininess was recorded as present in all twenty-one genotypes, indicating that the evaluated genotypes set uniformly expressed spiny inflorescences. This fixed expression of spininess in the present material contrasts with studies where spine absence or presence varied among accessions, suggesting that the current genotypes may belong to a spiny-type subgroup within the species. Siamey *et al.* (2025) ^[16] documented both spiny and spine-less inflorescences in earlier characterization experiments on amaranth germplasm. This emphasizes the importance of spine morphology as a distinguishing feature in grain amaranth.

Inflorescence compactness

Inflorescence compactness was classified as lax in EC033345, IC038468, IC313250, IC467913 and BGA-7; intermediate in RMA24-8, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5 and RMA-7; dense only in SUVARNA and BGA-2. The distribution of genotypes across three compactness classes (lax, intermediate and dense) underlines the presence of considerable morphological diversity, which can be exploited for breeding compact or open-head types suitable for mechanical harvesting. The results of inflorescence

compactness under study were same as the results of Varalakshmi *et al.* (2004) ^[1].

Inflorescence shape

Inflorescence shape was straight in EC033345, IC038468, IC313250, IC467913, RMA24-8, RMA24-17, RMA24-43, RMA24-62, BGA-41, SKNA-2003 and SKNA-2103, while AGR23-2, BGA-7, BGA47-1, BGA-24, SKNA-2105, SKNA-1902, GA-5, SUVARNA, BGA-2 and RMA-7 showed semi-drooping inflorescences. The coexistence of straight and semi-drooping forms in the same germplasm collection indicates genetic variability for inflorescence posture, which may influence seed retention and harvest efficiency. Kamini and RK Yadav (2023) ^[7] described similar qualitative distinctions in inflorescence shape (straight, semi-drooping and globose) in other grain amaranth morphology studies. This supports its use as a standard DUS trait for varietal identification.

Stem colour

Stem colour was pink in EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105 and GA-5 whereas IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-1902, SUVARNA, BGA-2 and RMA-7 exhibited yellowish-green stems. This colour polymorphism in stems, similar to findings in other grain amaranth characterization studies, reflects differences in anthocyanin or carotenoid accumulation and can serve as a reliable phenotypic marker for distinguishing genotypes. These results for stem colour were in accordance with the findings of Deepika *et al.* (2018) ^[2] and Ray *et al.* (2019) ^[15].

Stem surface

Stem surface from smooth and ridged EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105, GA-5 and SUVARNA were smooth, IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-1902, BGA-2 and RMA-7 were ridged. Labiba *et al.* (2018) also observed the similar findings for the character stem surface.

Seed colour

Seed colour was golden in EC033345 and IC313250, pale yellow in IC038468 and creamish in IC467913, RMA24-8, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-7, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105 SKNA-1902, GA-5, SUVARNA, BGA-2 and RMA-7. The presence of multiple seed-colour classes (golden, pale yellow and creamish) within the germplasm confirms seed colour as a highly polymorphic qualitative trait. Sravan *et al.* (2023) ^[4] described creamish, pale yellow and brownish seeds as common variants in other DUS-based grain amaranth characterization studies. This aligns with the observed seed color variation, confirming these as reliable morphological descriptors in grain amaranth germplasm.

Table 3: Qualitative character of grain amaranth genotypes based on descriptor

Character Genotype	Leaf blotch	Leaf blade main colour	Inflorescence colour	Inflorescence compactness	Inflorescence spininess	Inflorescence shape	Stem colour	Stem surface	Seed colour
EC033345	Absent	Purple	Pink	Lax	Present	Straight	Pink	Smooth	Golden
IC038468	Absent	Green	Yellowish Green	Lax	Present	Straight	Yellowish Green	Ridged	Pale yellow
IC313250	Present	Purple	Pink	Lax	Present	Straight	Pink	Smooth	Golden
IC467913	Absent	Green	Yellowish Green	Lax	Present	Straight	Yellowish Green	Ridged	Creamish
RMA24-8	Present	Purple	Pink	Intermediate	Present	Straight	Yellowish Green	Smooth	Creamish
RMA24-17	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
RMA24-43	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
RMA24-62	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
AGR23-2	Absent	Purple	Pink	Intermediate	Present	Semi drooping	Pink	Smooth	Creamish
BGA-7	Absent	Purple	Pink	Lax	Present	Semi drooping	Pink	Smooth	Creamish
BGA-41	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
BGA47-1	Absent	Green	Yellowish Green	Intermediate	Present	Semi drooping	Yellowish Green	Ridged	Creamish
BGA-24	Absent	Green	Yellowish Green	Intermediate	Present	Semi drooping	Yellowish Green	Ridged	Creamish
SKNA-2003	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
SKNA-2103	Absent	Green	Yellowish Green	Intermediate	Present	Straight	Yellowish Green	Ridged	Creamish
SKNA-2105	Absent	Purple	Yellowish Green	Intermediate	Present	Semi drooping	Yellowish Green	Smooth	Creamish
SKNA-1902	Absent	Green	Yellowish Green	Intermediate	Present	Semi drooping	Pink	Ridged	Creamish
GA-5	Absent	Purple	Yellowish Green	Intermediate	Present	Semi drooping	Yellowish Green	Smooth	Creamish
SUVARNA	Absent	Green	Pink	Dense	Present	Semi drooping	Pink	Smooth	Creamish
BGA-2	Absent	Green	Yellowish Green	Dense	Present	Semi drooping	Yellowish Green	Ridged	Creamish
RMA-7	Absent	Green	Pink	Intermediate	Present	Semi drooping	Yellowish Green	Ridged	Creamish

Table 4: Frequency distribution of Grain Amaranth genotypes for various DUS characters

S. N	Character	State of expression	No. of genotypes	Frequency distribution	Genotypes
1	Plant leaf blotch	Present	2	9.5	IC313250, RMA 24-8
		Absent	19	90.5	EC033345, IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-7, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5, SUVARNA, BGA-2, RMA-7
2	Leaf blade main colour	Purple	7	33	EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105, GA-5
		Green	14	67	IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-1902, SUVARNA, BGA-2, RMA-7
3	Inflorescence colour	Pink	7	33	EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, GA-5, RMA-7
		Yellowish green	14	67	IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, SUVARNA, RMA-7
4	Inflorescence spininess	Present	21	100	EC033345, IC038468, IC313250, IC467913, RMA24-8, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-7, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5, SUVARNA, BGA-2, RMA-7
		Absent	0	0	
5	Inflorescence Compactness	Lax	5	24	EC033345, IC038468, IC313250, IC467913, BGA-7
		Intermediate	14	67	RMA24-8, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5, RMA-7
		Dense	2	9	SUVARNA, BGA-2
6	Inflorescence shape	Straight	11	52	EC033345, IC038468, IC313250, IC467913, RMA24-8, RMA24-17, RMA24-43, RMA24-62, BGA-41, SKNA-2003, SKNA-2103
		Semi drooping	10	48	AGR23-2, BGA-7, BGA47-1, BGA-24, SKNA-2105, SKNA-1902, GA-5, SUVARNA, BGA-2, RMA-7
7	Stem colour	Pink	7	33	EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105, GA-5
		Yellowish green	14	67	IC038468, IC467913, RMA24-17, RMA24-43, RMA24-62, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-1902, SUVARNA, BGA-2, RMA-7
8	Stem Surface	Smooth	8	38	EC033345, IC313250, RMA24-8, AGR23-2, BGA-7, SKNA-2105, GA-5, SUVARNA
		Ridged	13	62	BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-1902, BGA-2, RMA-7
9	Seed colour	Golden	2	9	EC033345, IC313250
		Pale yellow	1	5	IC038468
		Creamish	18	86	IC467913, RMA24-8, RMA24-17, RMA24-43, RMA24-62, AGR23-2, BGA-7, BGA-41, BGA47-1, BGA-24, SKNA-2003, SKNA-2103, SKNA-2105, SKNA-1902, GA-5, BGA-2, RMA-7, SUVARNA

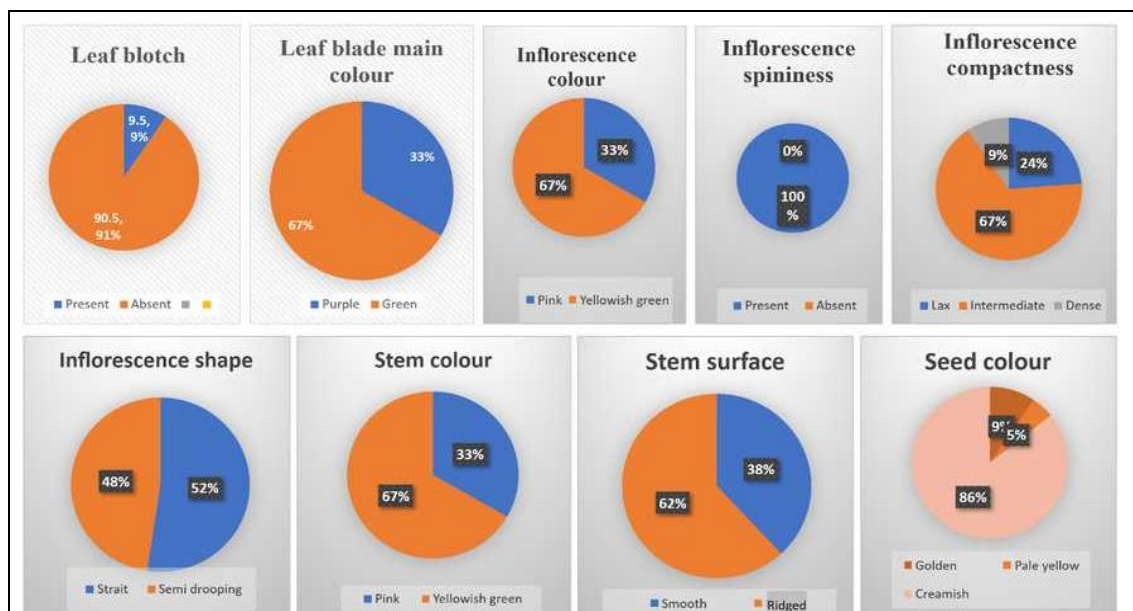


Fig 1: Pie chart frequency distribution of Grain Amaranth genotypes for various DUS characters

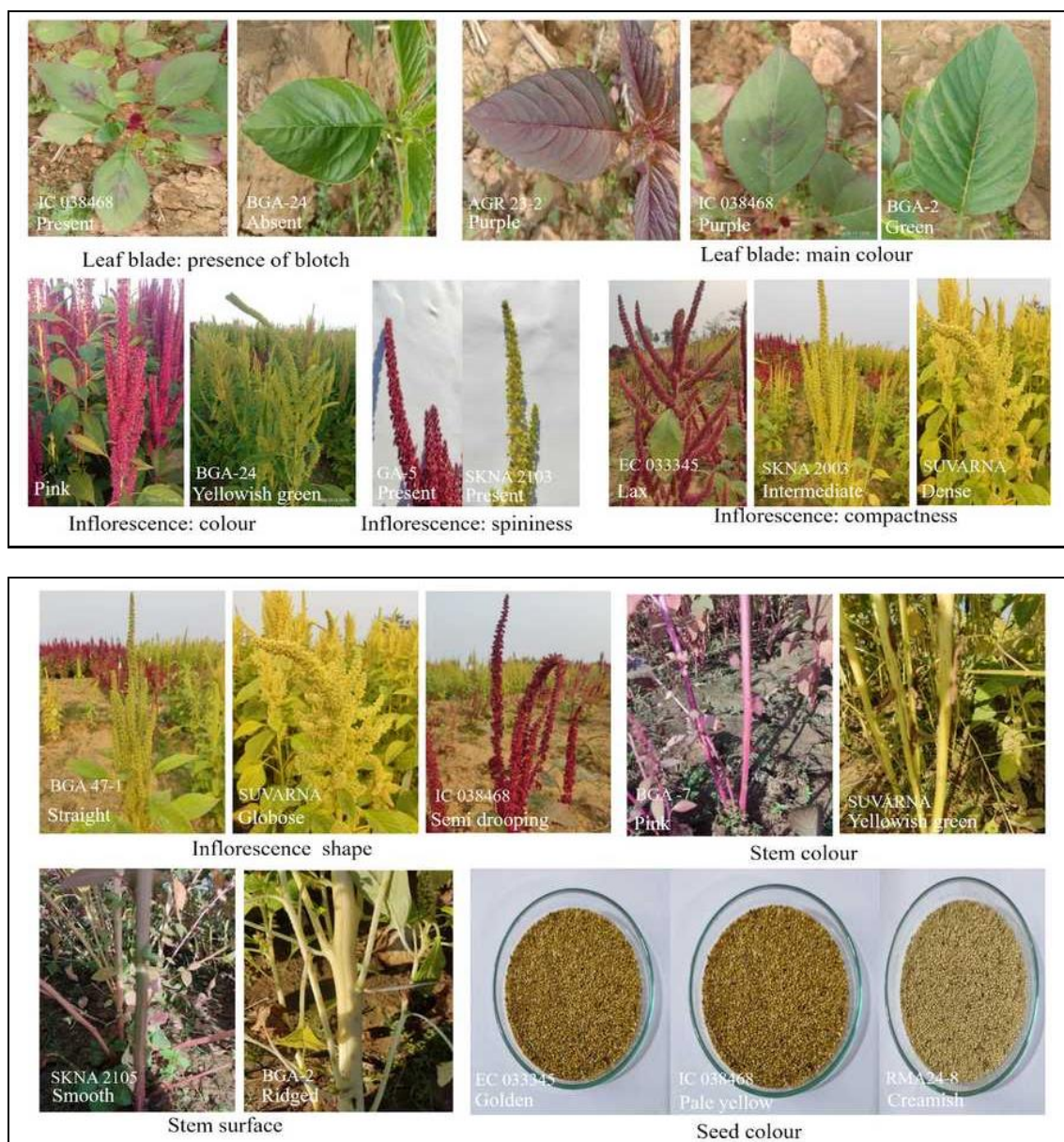


Plate 1: DUS Characterization of grain amaranth



Plate 2: Morphological variation in different genotypes in grain amaranth

Conclusion

The present study revealed substantial qualitative diversity among the 21 grain amaranth genotypes for a wide range of morphological traits, including plant leaf blotch, leaf blade colour, inflorescence colour and compactness, inflorescence shape, stem colour and surface, as well as seed colour. The clear segregation of genotypes into distinct phenotypic classes-such as purple versus green leaf blades, pink versus yellowish-green inflorescences, straight versus semi-drooping inflorescences, smooth versus rigid stems and different seed colour types (golden, pale yellow and creamish)-indicates marked genetic variability within the germplasm set. This variation can be effectively utilized for varietal differentiation, germplasm grouping, and selection of promising genotypes in breeding programmes.

The observed patterns of qualitative trait expression are closely aligned with earlier DUS-based characterization studies on grain amaranth, which likewise report polymorphism for leaf, inflorescence, stem and seed traits. Overall, the results demonstrate that these qualitative descriptors are reliable, visually distinguishable and stable enough to serve as practical tools for morphological characterization, genetic diversity analysis and germplasm conservation in grain amaranth.

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References

1. Varalakshmi B. Characterization and preliminary evaluation of vegetable amaranth (*Amaranthus* spp.) germplasm. Plant Genet Resour Newsl. 2004;137(1):55-57.
2. Chandravanshi D, Sharma PK, Sharma HG. Evaluation and characterization of leafy vegetables (*Amaranthus* spp. L.) grown in Chhattisgarh: a review. Int J Chem Stud. 2018;6(3):697-704.
3. Chatarmal SM, Kute NS. Stability analysis in grain amaranth (*Amaranthus hypochondriacus* L.). J Agric Res Technol. 2013;38(1):138-141.
4. Sravan D, RR K, Padma E, KM B. Study on morphological characterization of amaranthus (*Amaranthus* spp. L.) germplasm. Pharma Innovation J. 2023;12(9):1512-1515.
5. Downton WJS. *Amaranthus edulis*: a high lysine grain amaranth. World Crops. 1973;25:20.
6. Janssen F, Lambrecht R, McClements DJ, Vergauwen R, Kokini JL. Proteins of amaranth (*Amaranthus* spp.), buckwheat (*Fagopyrum* spp.), and quinoa (*Chenopodium* spp.): a food science and technology perspective. Compr Rev Food Sci Food Saf. 2017;16(2):280-300.
7. Kamini, Yadav RK. Agro-morphological characterization in grain amaranth (*Amaranthus hypochondriacus* L.). Pharma J. 2023;12(6):891-897.
8. Khoshoo TN, Pal M. Evolution and improvement of cultivated amaranths. Chromosomes Today. 1970;3:259-267.
9. Kumar Y, Prasad R, Singh PR. Studies on collection and evaluation of genetic variability available in *Amaranthus* (*Amaranthus* spp.) under Chhattisgarh plain condition. Int J Curr Microbiol Appl Sci. 2018;7(4):3540-3547.
10. Labiba RS, Baseerat A, Khan SH, Habib M. Morphological characterization of *Amaranthus* spp. under temperate environment using NBPGR descriptor. J Pharmacogn Phytochem. 2018;7(1):2716-2718.
11. Lagad SL, Zate DK, Borde YS, Deshmukh AA, Kalpande HZ. DUS characterization of grain amaranthus (*A. hypochondriacus*) for morphological traits. Pharma J. 2023;12(10):567-572.
12. Polaris Market Research. Global amaranth market size report 2025-2034. USA: Polaris Market Research; 2025.
13. Raiger HL, Jagoriya NK. Improved varieties, agro-techniques, potential uses of grain amaranth increase

- the yield and area in India and enhance the availability of nutritious food in human beings. *Just Agriculture*. 2024;5(1):159-168.
14. Rai N, Yadav SK. *Advances in Vegetable Production*. New Delhi: Researchco Book Centre; 2005.
 15. Ray R. Genetic variability studies in *Amaranthus* (*Amaranthus* spp.) [thesis]. Odisha: Odisha University of Agriculture and Technology; 2019.
 16. Siamey J, Amissah JN, Ofori PA, Amoah RA, Mensah EO, Kotey DA. Agro-morphological and molecular characterization of *Amaranthus* genotypes. *PLoS One*. 2025;20(9):e0328567.