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Assessment of genetic variability in indigenous rice germplasm based on morphological traits

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Abstract
Rice (*Oryza sativa* L.) is one of the most important staple food crops worldwide and serves as a major source of calories for a large proportion of the global population. Indigenous rice germplasm represents an important reservoir of genetic diversity containing valuable traits associated with grain yield, grain quality, biotic and abiotic stress tolerance, and environmental adaptation. The assessment of genetic variability in indigenous rice germplasm is essential for the identification, conservation and utilization of desirable genetic resources in rice improvement programmes. Morphological characterization is one of the most widely used approaches for evaluating genetic diversity because it is relatively simple, economical and suitable for large-scale field evaluation. Important morphological traits include plant height, number of tillers, panicle length, number of grains per panicle, grain size, grain shape, days to flowering, days to maturity and thousand-grain weight. These traits provide valuable information regarding genetic differences among rice accessions and their potential use in crop improvement. The use of standardized descriptors, multivariate statistical techniques, correlation analysis, principal component analysis (PCA) and cluster analysis has improved the accuracy of genetic variability assessment. Indigenous rice varieties, particularly traditional landraces, possess unique genetic characteristics that can be utilized to develop high-yielding, climate-resilient and nutritionally superior cultivars. This review highlights the importance of indigenous rice germplasm, major morphological traits used for variability assessment, characterization methods, statistical approaches, applications in rice breeding, existing challenges and future prospects.

Keywords: Indigenous rice germplasm, Genetic variability, Morphological traits, Rice landraces, Genetic diversity, Principal component analysis, Cluster analysis, Plant breeding

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and plays a significant role in global food and nutritional security. It is cultivated under diverse agro-ecological conditions, ranging from irrigated lowlands to rainfed uplands, deepwater ecosystems and coastal environments. Rice is a staple food for billions of people, particularly in Asia, where it contributes substantially to daily energy and nutritional requirements.

India is one of the major rice-producing countries and possesses enormous diversity in traditional rice varieties. Indigenous rice germplasm includes traditional landraces, farmer-maintained varieties, locally adapted populations and other genetic resources developed and conserved through generations of cultivation and natural selection.

These indigenous varieties represent an important source of genetic variability for desirable agronomic and quality traits. Many traditional rice varieties possess unique characteristics such as drought tolerance, flood tolerance, salinity tolerance, disease resistance, insect resistance, aroma, medicinal properties and adaptability to specific ecological conditions.

However, the replacement of traditional varieties by modern high-yielding cultivars, changes in agricultural practices and habitat transformation have contributed to the gradual loss of indigenous rice diversity in several regions.

Genetic variability is the basic requirement for crop improvement because selection and breeding depend on the availability of heritable differences among genotypes. Assessment of genetic variability helps plant breeders identify genetically diverse parents and select promising accessions for hybridization programmes.

Morphological characterization is an important preliminary step in the evaluation of rice germplasm. It involves the systematic observation and measurement of plant characteristics during different growth stages. Morphological traits are useful because they are directly associated with plant growth, development, yield potential and adaptation to environmental conditions.

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The International Rice Research Institute (IRRI) and Bioversity International have developed standardized rice descriptors to facilitate the systematic characterization and evaluation of rice genetic resources.
The integration of morphological characterization with molecular marker technology can provide a more comprehensive understanding of genetic diversity and improve the efficiency of rice breeding programmes.
The present review discusses the assessment of genetic variability in indigenous rice germplasm based on morphological traits, with particular emphasis on characterization methods, statistical approaches, breeding applications and future prospects.

2. Importance of indigenous rice germplasm

Indigenous rice germplasm represents a valuable genetic resource for sustainable rice improvement. Traditional varieties have evolved under different environmental conditions and farmer selection practices, resulting in considerable genetic variation.
The importance of indigenous rice germplasm can be understood through the following aspects.

2.1 Source of genetic diversity

Traditional rice varieties contain a wide range of genetic characteristics associated with plant architecture, flowering, maturity, grain quality and yield components.
This genetic diversity provides opportunities for identifying desirable parents and broadening the genetic base of modern rice cultivars.

2.2 Source of abiotic stress tolerance

Indigenous rice varieties adapted to particular environments may possess valuable tolerance mechanisms against:

- Drought stress.
- Flooding and submergence.
- Soil salinity.
- High temperature.
- Low-temperature stress.
- Nutrient-deficient soils.

For example, traditional flood-adapted rice germplasm has been an important source of genetic resources for developing submergence-tolerant rice cultivars.

2.3 Resistance to biotic stresses

Traditional varieties may contain useful resistance traits against major rice pests and diseases, including:

- Brown planthopper.
- Stem borer.
- Bacterial leaf blight.
- Blast disease.
- Sheath blight.
- Rice tungro disease.

Characterization of indigenous germplasm helps identify promising accessions for resistance breeding.

2.4 Improvement of grain quality

Several indigenous rice varieties possess unique grain and nutritional characteristics, including aroma, attractive grain appearance, desirable cooking quality and special nutritional properties.
These varieties can be utilized in breeding programmes aimed at improving consumer preference and market value.

2.5 Conservation of traditional genetic resources

Characterization and documentation of indigenous rice varieties are important for conserving agricultural biodiversity.
Systematic evaluation helps identify valuable accessions that require conservation in seed banks, field gene banks and farmers' traditional production systems.

3. Concept of genetic variability in rice germplasm

Genetic variability refers to the heritable differences among individuals or populations within a species.
In rice, genetic variability is expressed through differences in morphological, physiological, biochemical and molecular characteristics.
The extent of genetic variability determines the potential for genetic improvement through selection and hybridization.

3.1 Genetic and phenotypic variability

Phenotypic variability represents the observable differences among rice genotypes, while genetic variability refers to differences arising from their genetic constitution.
Phenotypic expression is influenced by genotype, environment and genotype-by-environment interaction.
The phenotypic expression of a trait can be represented as:

$$P = G + E + G \times E$$

Where:

- P = Phenotypic value.
- G = Genotypic effect.
- E = Environmental effect.
- $G \times E$ = Genotype-environment interaction.

Therefore, morphological characterization should preferably be conducted under uniform experimental conditions and repeated across seasons or locations.

3.2 Importance of genetic variability assessment

Assessment of genetic variability provides information regarding:

1. Identification of superior rice genotypes.
2. Selection of diverse parents for hybridization.
3. Identification of desirable morphological traits.
4. Development of high-yielding cultivars.
5. Conservation of indigenous germplasm.
6. Identification of genotypes adapted to specific environments.
7. Improvement of grain quality and nutritional characteristics.

4. Important morphological traits used for characterization of rice germplasm

Morphological characterization involves the systematic observation of qualitative and quantitative traits.

4.1 Plant height

Plant height is an important morphological trait that influences crop architecture, lodging resistance and biomass production.
It is generally measured from the soil surface to the tip of the tallest panicle, excluding awns.
Rice genotypes exhibit considerable variation in plant height, which may be classified broadly as:

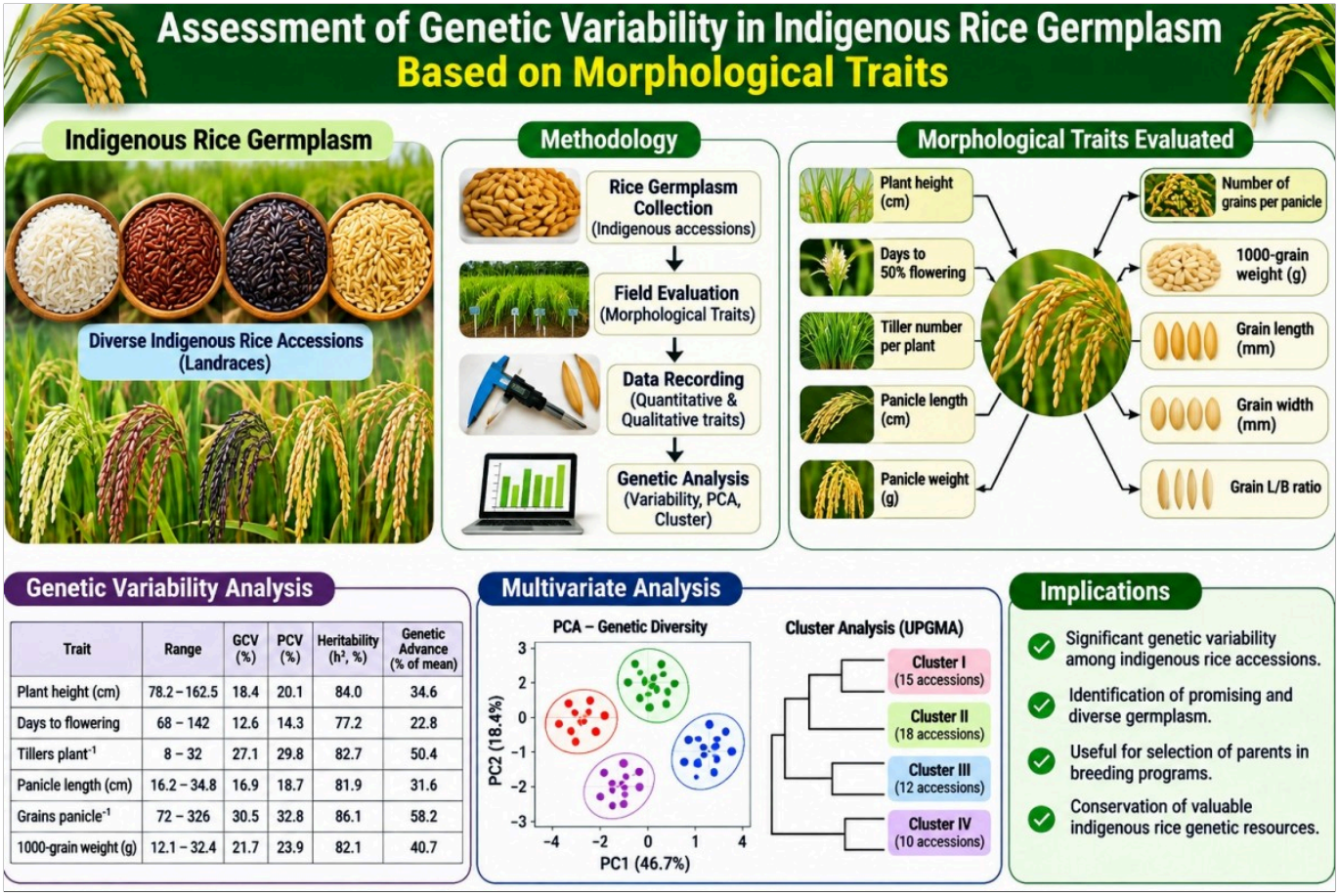
- Dwarf.
- Semi-dwarf.
- Intermediate.
- Tall.

Semi-dwarf plant types are particularly important in modern rice breeding because of their improved lodging resistance and suitability for high-input production systems.

4.2 Number of tillers per plant

Tillering capacity is an important yield-related trait in rice.
The number of productive tillers directly contributes to panicle number per unit area and ultimately influences grain yield.

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Trait	Range	GCV (%)	PCV (%)	Heritability (h^2, %)	Genetic Advance (% of mean)
Plant height (cm)	78.2 – 162.5	18.4	20.1	84.0	34.6
Days to flowering	68 – 142	12.6	14.3	77.2	22.8
Tillers plant^{-1}	8 – 32	27.1	29.8	82.7	50.4
Panicle length (cm)	16.2 – 34.8	16.9	18.7	81.9	31.6
Grains panicle^{-1}	72 – 326	30.5	32.8	86.1	58.2
1000-grain weight (g)	12.1 – 32.4	21.7	23.9	82.1	40.7

Figure 1. Assessment of Genetic Variability in Indigenous Rice Germplasm Based on Morphological Traits

Indigenous rice accessions may differ considerably in total tiller number, productive tillers and tiller angle.

4.3 Leaf characteristics

Leaf morphology is useful for understanding varietal differences and canopy architecture.

Important leaf traits include:

- Leaf length.
- Leaf width.
- Leaf angle.
- Leaf colour.
- Leaf pubescence.
- Flag leaf length.
- Flag leaf width.

Flag leaf characteristics are particularly important because the flag leaf contributes significantly to photosynthesis during grain filling.

4.4 Days to 50% flowering

Days to 50% flowering indicate the time required for approximately half of the plants in a population to produce flowers.

This trait is important for determining the maturity duration and environmental adaptation of rice genotypes.

Early-flowering genotypes may be useful in short-duration cropping systems, while medium- and long-duration varieties may be suitable for different agro-ecological conditions.

4.5 Days to maturity

Days to maturity represent the duration from sowing or transplanting to physiological maturity.

This trait is important for selecting varieties suitable for different cropping systems and seasonal conditions.

4.6 Panicle length

Panicle length is an important yield-related morphological character.

It is generally measured from the panicle base to the tip of the uppermost grain-bearing branch.

Longer panicles may provide greater potential for spikelet production, although panicle length alone does not determine grain yield.

4.7 Number of grains per panicle

The number of grains per panicle is an important yield component influenced by genetic factors and environmental conditions.

It is generally assessed by counting filled and unfilled spikelets separately.

Genotypes with a higher number of filled grains may have greater yield potential when supported by adequate grain filling.

4.8 Grain size and grain shape

Grain size and shape are important morphological traits that determine market preference and consumer acceptance.

Common grain categories include:

- Long slender.
- Medium slender.
- Short slender.
- Long bold.
- Medium bold.

Grain length, grain breadth and the length-to-breadth ratio are commonly measured during germplasm evaluation.

4.9 Thousand-grain weight

Thousand-grain weight is an important yield component that reflects grain size and grain development.

It is generally expressed in grams and measured using a representative sample of mature, clean grains.

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4.10 Awn and grain colour

Awn presence, awn length, awn colour, lemma and palea colour, and grain pericarp colour are useful qualitative traits for distinguishing traditional rice accessions.

These characteristics can also help identify unique indigenous varieties.

5. Qualitative and quantitative morphological traits

Morphological traits used in rice germplasm evaluation can broadly be divided into qualitative and quantitative characters.

5.1 Qualitative traits

Qualitative traits are generally controlled by one or a few genes and are expressed in distinct categories.

Important qualitative traits include:

- Leaf blade colour.
- Leaf sheath colour.
- Auricle colour.
- Ligule shape.
- Ligule colour.
- Presence or absence of awns.
- Awn colour.
- Grain pericarp colour.
- Lemma and palea colour.
- Stigma colour.
- Apiculus colour.
- Grain aroma.

These traits are useful for varietal identification, classification and preliminary diversity assessment.

5.2 Quantitative traits

Quantitative traits show continuous variation and are generally controlled by multiple genes.

Important quantitative traits include:

- Plant height (cm).
- Number of tillers per plant.
- Number of productive tillers per plant.
- Leaf length (cm).
- Leaf width (cm).
- Days to 50% flowering.
- Days to maturity.
- Panicle length (cm).
- Number of grains per panicle.
- Grain length (mm).
- Grain breadth (mm).
- Thousand-grain weight (g).
- Grain yield per plant (g).

Quantitative traits are particularly important for identifying promising genotypes for crop improvement.

6. Methods of morphological characterization of indigenous rice germplasm

Systematic characterization requires standardized experimental procedures to ensure reliable comparisons among rice accessions.

6.1 Collection of indigenous rice germplasm

The first step involves collecting traditional rice varieties from different geographical regions and agro-climatic zones.

Germplasm may be collected from:

- Farmers' fields.
- Traditional rice-growing villages.
- Agricultural universities.
- National gene banks.
- State agricultural research stations.
- Indigenous farming communities.

Each accession should be assigned a unique identification number, and information regarding its geographical origin, collection location, farmer name, local name and traditional characteristics should be recorded.

6.2 Experimental design

Collected accessions should be evaluated in a field experiment using an appropriate experimental design.

Commonly used experimental designs include:

1. Randomized Block Design (RBD).
2. Augmented Block Design.
3. Alpha Lattice Design.
4. Completely Randomized Design (for suitable controlled evaluations).

For a large collection of indigenous rice accessions, an augmented block design may be useful when sufficient replications are not feasible for every genotype.

6.3 Field evaluation

Rice germplasm should be evaluated under uniform agronomic conditions.

Important field management practices include:

- Uniform seed treatment and nursery raising.
- Standardized transplanting age.
- Uniform spacing.
- Recommended fertilizer application.
- Appropriate irrigation management.
- Timely weed management.
- Effective pest and disease management.

Observations should be recorded at appropriate growth stages, including vegetative, reproductive and maturity stages.

6.4 Measurement of morphological traits

Qualitative and quantitative characters should be recorded using standardized rice descriptors.

For example:

6.5 Standardized rice descriptors

The use of standardized descriptors is important for obtaining reliable and comparable results.

The International Rice Research Institute (IRRI) has developed rice evaluation and characterization guidelines that support systematic documentation of morphological characteristics.

Morphological trait	Unit/observation
Plant height	cm
Number of tillers	Number/plant
Productive tillers	Number/plant
Leaf length	cm
Leaf width	cm
Days to 50% flowering	Days
Days to maturity	Days
Panicle length	cm
Grains per panicle	Number

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Morphological trait	Unit/observation
Grain length	mm
Grain breadth	mm
Thousand-grain weight	g
Grain yield per plant	g
Awn	Present/Absent
Grain colour	Descriptor category

Standardized characterization improves the accuracy of germplasm identification and facilitates the exchange of information among research institutions.

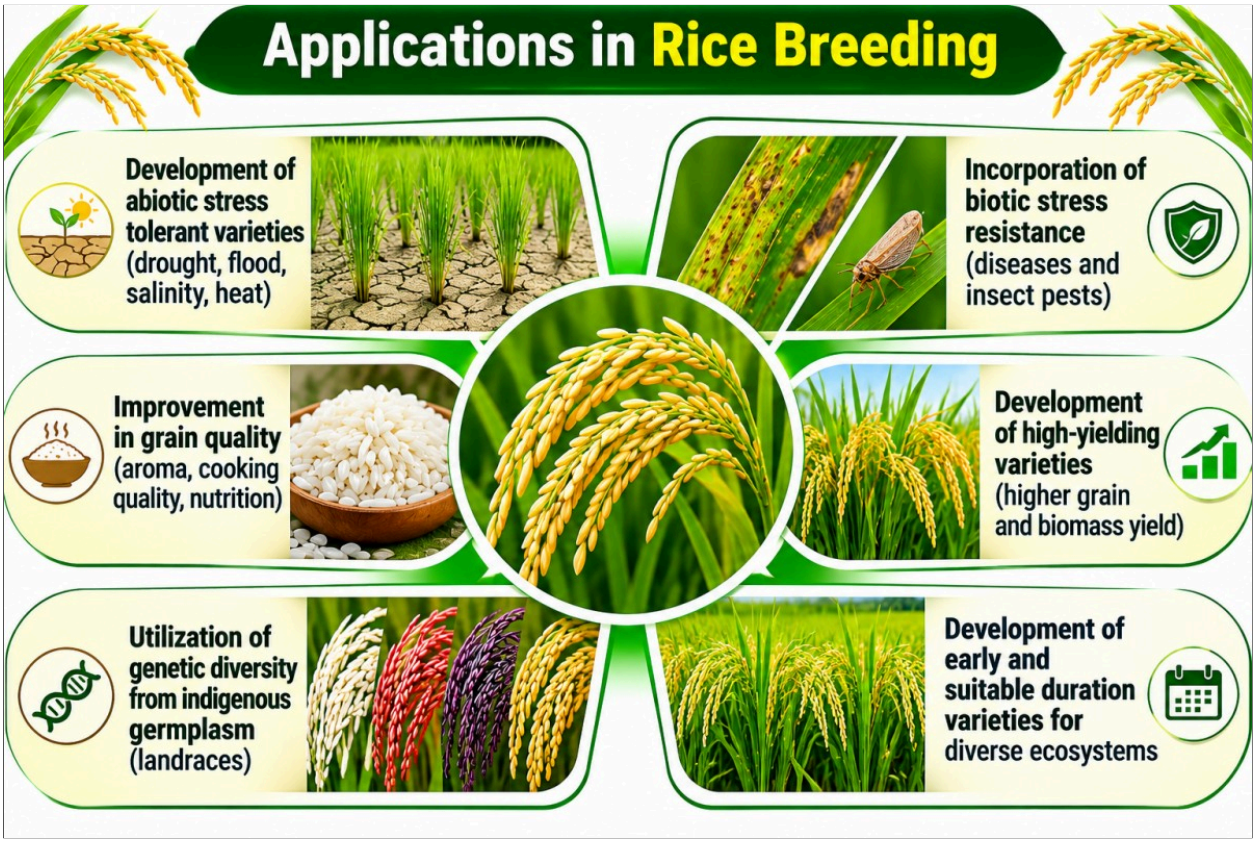


Figure 2. Application in rice breeding

7. Statistical approaches for assessing genetic variability

Statistical analysis plays a major role in identifying the extent and pattern of genetic variability among indigenous rice accessions.

7.1 Analysis of variance (ANOVA)

Analysis of variance is used to determine whether significant differences exist among rice genotypes for different morphological traits.
Significant genotypic differences indicate the presence of phenotypic variability within the evaluated germplasm collection.
ANOVA can be used to assess variation in plant height, tiller number, flowering duration, panicle length, grain weight and grain yield.

7.2 Genotypic and phenotypic coefficient of variation

Genotypic coefficient of variation (*GCV*) and phenotypic coefficient of variation (*PCV*) are important statistical parameters for assessing variability.
The formula for *GCV* is:

$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{X}} \times 100$$

The formula for *PCV* is:

$$PCV = \frac{\sqrt{\sigma_p^2}}{\bar{X}} \times 100$$

Where:

- σ_g^2 = Genotypic variance.
- σ_p^2 = Phenotypic variance.
- $\bar{X}$ = Population mean.

A relatively small difference between *PCV* and *GCV* indicates that environmental effects on the expression of the trait are comparatively limited.

7.3 Heritability

Heritability estimates the proportion of observed phenotypic variation attributable to genetic variation under the specified population and experimental conditions.
Broad-sense heritability is calculated as:

$$H^2 = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

High heritability suggests that genetic factors explain a large proportion of observed variation. However, heritability alone does not establish the expected response to selection.

7.4 Genetic advance

Genetic advance estimates the expected improvement in a trait following selection.

$$GA = K \times \sigma_p \times H^2$$

Where:

- *GA* = Genetic advance.
- *K* = Selection differential (approximately 2.06 for 5% selection intensity).
- σ_p = Phenotypic standard deviation.
- H^2 = Heritability expressed as a proportion.

Genetic advance as a percentage of the mean is calculated as:

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$$GAM = \frac{GA}{\bar{X}} \times 100$$

High heritability combined with high genetic advance may indicate the importance of additive genetic effects and the potential effectiveness of selection. Interpretation should consider the experimental design and genetic population.

7.5 Correlation analysis

Correlation analysis is used to determine the degree and direction of association between different morphological and yield-related traits.
For example, grain yield may be positively associated with productive tillers, filled grains per panicle and thousand-grain weight.
Correlation analysis helps identify traits that can be used as indirect selection criteria in rice improvement programmes.

7.6 Principal component analysis (PCA)

Principal component analysis is a multivariate statistical technique used to reduce a large number of correlated variables into a smaller number of independent components.
PCA identifies the traits contributing most to the total variation among rice accessions.
It is useful for:

- Identifying important morphological traits.
- Understanding relationships among variables.
- Detecting major sources of variation.
- Visualizing diversity patterns.
- Selecting promising genotypes for breeding.

7.7 Cluster analysis

Cluster analysis groups rice genotypes according to similarities and differences in their morphological characteristics.
Genotypes within the same cluster generally exhibit greater similarity, while genotypes in different clusters may show greater morphological divergence.
Common methods include:

- Ward's minimum variance method.
- UPGMA.
- Complete linkage clustering.
- Euclidean distance-based clustering.

Cluster analysis helps identify diverse parental combinations for future hybridization programmes.

8. Role of morphological variability in rice breeding

Morphological variability assessment provides a foundation for selecting promising genotypes and developing improved rice cultivars.

8.1 Selection of superior genotypes

Morphological evaluation helps identify accessions with desirable combinations of plant height, tillering ability, panicle characteristics, grain weight and yield.
Selected accessions can be further evaluated for their performance across different locations and seasons.

8.2 Identification of diverse parents

Genetically diverse parents are important for developing segregating populations with broad genetic variation.
Cluster analysis and genetic distance estimates can help breeders identify contrasting parents for hybridization.
However, morphological divergence should be supplemented with molecular and pedigree information where possible.

8.3 Improvement of yield components

Morphological traits such as productive tillers, panicle length, filled grains per panicle and thousand-grain weight are important components of rice yield.
Selection for favourable combinations of these traits can contribute to the development of high-yielding varieties.

8.4 Development of climate-resilient varieties

Indigenous germplasm adapted to specific environments may possess valuable traits associated with drought, flooding, salinity and heat tolerance.
These accessions can be used as donor parents for developing climate-resilient rice cultivars.

8.5 Improvement of grain quality

Morphological characterization of grain length, breadth, shape, colour and aroma helps identify varieties with desirable grain quality characteristics.
These traits are important for developing rice cultivars that meet consumer preferences and market requirements.

9. Major findings from previous studies on indigenous rice germplasm

Several studies conducted in India and other rice-growing regions have demonstrated considerable morphological diversity among indigenous rice germplasm.

9.1 Genetic diversity of South Indian rice landraces

Mani *et al.* (2014) [1] evaluated 49 local rice landraces from southwestern India for genetic variability and diversity based on morphological traits. The study reported considerable variation in number of grains, spikelets, harvest index, test weight and productive tillers. Cluster analysis revealed five distinct groups, indicating the presence of useful diversity for rice improvement.
Indian Journals

9.2 Assessment of morphological diversity in rice germplasm from North-West India

Sharma *et al.* evaluated 2,142 rice accessions using ten agro-morphological traits. The genotypes were grouped into eight clusters. Principal component analysis identified plant height, flowering and maturity duration, effective tillers and grain characteristics as important traits contributing to phenotypic variation. The findings demonstrated the usefulness of large-scale germplasm characterization for identifying diverse breeding materials.
The Indian Journal of Agricultural Sciences

9.3 Characterization of indigenous rice germplasm from Nagaland

A study of 124 indigenous rice landraces collected from Nagaland revealed substantial variation in plant architecture, grain morphology and quality characteristics. Principal component analysis explained 75.4% of the total variation through 12 components, while cluster analysis grouped the accessions into five major clusters. This study highlighted the importance of conserving northeastern Indian rice diversity.
Cambridge Core

9.4 Morphological characterization of rice landraces from West Bengal

Chakravorty *et al.* (2012) [2] evaluated 51 rice landraces using 18 agro-morphological traits over three Kharif seasons. Significant variation was observed among the accessions. Principal component analysis identified leaf length, culm number, culm diameter, number of grains per panicle and grain dimensions as important contributors to diversity. Ten major clusters were identified through cluster analysis.
Journal JEAI

9.5 Agro-morphological characterization of rice landraces and cultivars

Jegadeeswaran *et al.* (2017) [3] evaluated 152 rice genotypes comprising landraces, traditional varieties, exotic lines and released cultivars. Principal component analysis identified four major components explaining 74.90% of total variation. Cluster analysis revealed five distinct groups, demonstrating the usefulness of morphological characterization for selecting diverse parents in rice breeding.

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Indian Journals

9.6 Genetic diversity of South Indian rice landraces based on yield components

Shanmugam *et al.* evaluated 60 traditional rice landraces using 14 morphological traits. The genotypes were grouped into eight clusters, and the first five principal components explained 74.41% of the total variation. Number of grains per panicle, flag leaf length, kernel length, length-to-breadth ratio and hundred-seed weight were identified as important traits for yield improvement.
ejplantbreeding.org

9.7 Combined morphological and molecular diversity assessment

Kunusoth *et al.* (2015) [4] evaluated 24 elite Indian rice varieties using 24 agro-morphological traits and 86 SSR markers. The study found a positive and significant correlation between morphological and molecular diversity estimates, although the two approaches did not produce completely identical clustering patterns. This demonstrates the value of combining morphological and molecular characterization.
Journal JEAI

Summary of important studies

Study	Germplasm evaluated	Major findings
Mani *et al.* (2014) [1]	49 landraces	Five clusters; variation in yield components
Sharma *et al.*	2,142 accessions	Eight clusters; major agro-morphological diversity
Nagaland landrace study	124 accessions	Five clusters; 75.4% variation explained
Chakravorty *et al.* (2012) [2]	51 landraces	Ten clusters; variation in 18 traits
Jegadeeswaran *et al.* (2017) [3]	152 genotypes	Five clusters; 74.90% variation explained
Shanmugam *et al.*	60 landraces	Eight clusters; 74.41% variation explained
Kunusoth *et al.* (2015) [4]	24 varieties	Morphological and SSR diversity assessment

These studies collectively establish that indigenous rice germplasm contains substantial morphological variation that can be exploited in crop improvement programmes.

10. Indigenous rice germplasm and its importance in Indian agriculture

India possesses a rich collection of indigenous rice varieties adapted to different agro-climatic regions.
Traditional rice varieties have been maintained by farming communities through generations of seed selection and conservation.
Several indigenous rice varieties are recognized for their unique morphological, nutritional and adaptive characteristics.
Examples include:

- Kalanamak: Traditional aromatic rice associated with Uttar Pradesh.
- Jeeraphool: Aromatic rice traditionally cultivated in Chhattisgarh.
- Dubraj: Traditional aromatic rice of Chhattisgarh.
- Basmati: A group of premium aromatic long-grain rice varieties.
- Navara: Traditional medicinally valued rice of Kerala.
- Kagga: Traditional rice adapted to coastal environments of Karnataka.
- Black rice: Pigmented rice types valued for their anthocyanin content.
- Red rice: Traditional rice types characterized by coloured pericarp.

The conservation and characterization of these varieties are important for maintaining genetic diversity and identifying desirable traits for future breeding programmes.

10.1 Importance in Chhattisgarh

Chhattisgarh is known for its rich traditional rice diversity and is often recognized for its distinctive rice-growing heritage.
The state contains numerous farmer-maintained rice varieties adapted to rainfed, irrigated, upland and lowland production systems.
Morphological characterization of indigenous rice germplasm from Chhattisgarh can help identify promising accessions possessing:

- Early and medium maturity.
- High productive tillering capacity.
- Long and compact panicles.
- Improved grain quality.
- Drought adaptation.
- Submergence tolerance.
- Resistance to important pests and diseases.
- Suitability for rainfed production systems.

Systematic documentation of these varieties can support state-level germplasm conservation, breeding and the development of location-specific rice cultivars.

11. Limitations of morphological characterization

Although morphological characterization is a valuable approach for evaluating genetic diversity, it has several limitations.

11.1 Environmental influence

Morphological traits are often influenced by temperature, rainfall, soil fertility, moisture availability and crop management practices.
Therefore, the same genotype may show different phenotypic expressions under different environments.

11.2 Limited number of distinguishable traits

Some genetically different rice accessions may exhibit similar morphological characteristics.
Consequently, morphological characterization alone may not reveal the complete genetic diversity present within germplasm collections.

11.3 Genotype-by-environment interaction

Genotype-by-environment interaction may affect the stability and expression of quantitative traits.
Multi-location and multi-season evaluations are necessary for identifying stable and broadly adapted genotypes.

11.4 Time-consuming evaluation

Several morphological traits can only be recorded at specific growth stages. Complete characterization therefore requires a full crop-growing season.

11.5 Subjective assessment

Qualitative traits such as grain colour, leaf pigmentation, awn characteristics and aroma may be influenced by observation methods and evaluator experience.
Standardized descriptor scales and trained evaluators are important for minimizing subjective variation.

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11.6 Difficulty in assessing hidden genetic variation

Morphological characterization cannot directly identify all DNA-level differences, including variation in genes that are not expressed under the conditions of evaluation.

Therefore, molecular characterization should complement morphological assessment.

12. Integration of morphological and molecular characterization

The integration of morphological characterization with molecular marker technology provides a more comprehensive approach to assessing genetic diversity in rice.

Morphological characterization evaluates observable phenotypic differences, whereas molecular markers identify genetic variation directly at the DNA level.

Important molecular marker techniques used in rice include:

- Simple sequence repeats (SSR).
- Single nucleotide polymorphisms (SNP).
- Amplified fragment length polymorphism (AFLP).
- Inter-simple sequence repeats (ISSR).
- Genotyping-by-sequencing (GBS).

12.1 Advantages of combined characterization

1. More comprehensive assessment of genetic diversity.
2. Identification of genetically distinct accessions.
3. Better selection of parents for hybridization.
4. Identification of duplicate germplasm accessions.
5. Detection of hidden genetic variation.
6. Improved conservation and utilization of genetic resources.

The combination of morphological and molecular approaches can also help identify promising indigenous rice accessions for breeding programmes targeting yield, grain quality and stress tolerance.

13. Conclusion

Assessment of genetic variability in indigenous rice germplasm based on morphological traits is an important component of rice genetic improvement and conservation programmes. Traditional rice varieties represent a valuable source of genetic diversity for improving yield, grain quality, plant architecture, maturity duration and adaptation to different environmental conditions.

Morphological characterization using qualitative and quantitative traits provides useful information regarding genetic differences among rice accessions. Traits such as plant height, productive tillers, panicle length, grains per panicle, flowering duration, grain dimensions and thousand-grain weight are particularly important for identifying promising genotypes.

Statistical approaches such as analysis of variance, genotypic and phenotypic coefficients of variation, heritability, genetic advance, correlation analysis, principal component analysis and cluster analysis improve the interpretation of genetic variability and help identify diverse parental combinations.

However, morphological traits are influenced by environmental conditions, and therefore their evaluation should be supported by multi-location trials and molecular characterization.

Indigenous rice germplasm from India, particularly traditional varieties of Chhattisgarh and other rice-growing states, represents an important resource for future crop improvement. Systematic characterization, conservation and utilization of these genetic resources can contribute to the development of high-yielding, climate-resilient and nutritionally superior rice cultivars.

Overall, the integration of morphological, molecular and advanced phenotyping approaches will strengthen rice breeding programmes and contribute to sustainable agriculture and long-term food security.

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