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Genetic variability and heritability in advanced rice (*Oryza sativa* L.) strains under heterogeneous environments

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Abstract

Rice (*Oryza sativa* L.) plays a pivotal role in global food security, feeding more than half of the world's population. To sustain rising demands amidst climate change, population growth, and resource constraints, enhancing yield potential and trait stability in rice is imperative. This study investigates the magnitude of genetic variability, heritability, genetic advance, and correlation among 27 advanced rice genotypes across three heterogeneous environments. Using a randomized block design, phenotypic and genotypic coefficients of variation, broad-sense heritability, genetic advance as percent of mean, and correlation and path coefficient analyses were conducted. Significant differences among genotypes were observed for all measured traits, including yield. High heritability with high genetic advance was noted for productive tillers, biological yield, and fertile spikelets, indicating the predominance of additive gene effects. Path coefficient analysis revealed biological yield and spikelet fertility as the most influential contributors to yield. This study provides a statistical foundation for informed varietal selection and breeding in diverse environments to improve yield and sustainability in rice.

Keywords: Rice (*Oryza sativa* L.), genetic variability, heritability, genetic advance

1. Introduction

1.1 Global Importance of Rice

Rice is a cornerstone of food security and agricultural livelihoods, particularly in Asia, where over 90% of global rice production and consumption occur. India alone produces over 120 million tonnes annually, contributing nearly 23% of global output. In regions like Uttar Pradesh, which cultivates over 5.87 million hectares of rice, yield enhancement is essential to meet future demand and reduce reliance on imports.

1.2 Need for Genetic Improvement

Despite technological advancements, productivity remains constrained by the lack of genetically diverse, high-yielding, and climate-resilient varieties. The assessment of genetic variability and heritability is a foundational step toward developing such cultivars. Heritability offers insight into the proportion of trait variation due to genetic causes, while genetic advance reflects the expected improvement under selection.

1.3 Role of Multi-Trait and Multi-Environment Analysis

Agronomic traits such as productive tillers, grain size, panicle length, and harvest index directly impact yield. Their genetic parameters must be studied under real field conditions across varied environments to ensure selection effectiveness. Path coefficient and correlation analyses help breeders identify yield-contributing traits and prioritize them for selection.

2. Literature Review

Numerous studies affirm the value of GCV, heritability, and path analysis in rice breeding:

- Manjunatha *et al.* (2019) found high GCV and PCV in spikelet number and panicle traits, suggesting potential for direct selection.
- Basavaraja *et al.* (2013) ^[1] emphasized that traits with high heritability and genetic advance (e.g., grain yield and productive tillers) respond well to selection.

- Zahid *et al.* (2006) ^[11] noted strong direct effects of productive tillers and spikelet fertility on yield, highlighting their importance in breeding indices.
- Islam *et al.* (2019) recorded heritability estimates ranging from 71% to 99%, reinforcing the reliability of phenotypic selection for traits like filled grains and plant height.
- Rathod *et al.* (2020) ^[8] also reported that indirect effects via panicle length and spikelet number significantly impact grain yield.

These findings underscore the value of robust genetic parameter studies for sustainable rice improvement.

3. Materials and Methods

3.1 Experimental Design

The field trials were conducted during the Kharif 2019 season at three locations under the jurisdiction of ANDUA&T, Ayodhya:

- **E1:** Rainfed and low-fertility soil
- **E2:** Saline-sodic soil
- **E3:** Normal irrigated soil
- **Design:** Randomized Block Design
- **Replications:** 3
- **Treatments:** 27 genotypes (25 advanced strains + 2 checks: Pusa-44 and Sarjoo-52)

3.2 List of Genotypes

The 27 genotypes include popular and advanced lines such as:

- CSR1143
- CSR1620
- Kalanamak
- Pusa Basmati-1
- Sahi Dawat
- Damini Delta
- DRR Dhan-44

3.3 Soil and Climate Data

Soils ranged from slightly alkaline (pH 8.1-9.5). Weather data during the crop cycle (June-November) included:

- **Max temp:** 34.5 °C
- **Min temp:** 12.3 °C
- **Rainfall:** Up to 168.5 mm/week
- **Relative humidity:** 62-87%

3.4 Observations Recorded

Fifteen traits were evaluated:

1. Days to 50% flowering
2. Plant height
3. Productive tillers
4. Panicle length
5. Leaf area index

6. Fertile spikelets
7. Spikelet fertility (%)
8. Biological yield
9. Harvest index
10. Grain yield
11. 1000-grain weight
12. L/B ratio
13. Panicle number
14. Flag leaf length
15. Tiller height

3.5 Statistical Analysis

- GCV/PCV: Burton and de Vane (1953) ^[2-3]
- Heritability: Hanson *et al.* (1956) ^[5]
- Genetic Advance: Robinson *et al.* (1949) ^[9]
- Correlation and Path Analysis: Dewey and Lu (1959) ^[4]
- ANOVA: Panse and Sukhatme (1967) ^[7]
- Cluster analysis: Euclidean non-hierarchical method

4. Results and Interpretation (Expanded)

This section delves into the core findings from the study, interpreting the performance of rice genotypes across multiple genetic parameters.

4.1 Analysis of Variance (ANOVA)

The ANOVA results indicated highly significant differences ($p < 0.01$) among the genotypes for all measured traits across locations. This suggests that a broad spectrum of genetic variability exists in the studied material, which is a prerequisite for effective selection.

Table 1: ANOVA Summary for Key Traits

Trait	Mean Square (Genotypes)	Significance Level
Days to 50% flowering	95.42	Highly significant
Plant height	127.83	Highly significant
Productive tillers	14.12	Highly significant
Grain yield	78.41	Highly significant
Spikelet fertility	21.35	Highly significant

These results confirm substantial genotypic influence over the phenotypic expression of these traits.

4.2 Genetic Parameters: GCV, PCV, Heritability, and Genetic Advance

Genetic parameters are crucial for estimating the extent of environmental and genetic contribution to phenotypic traits.

- Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV) help determine variability.
- Heritability (broad sense) indicates the proportion of phenotypic variance attributable to genetics.
- Genetic Advance as Percent of Mean (GAM) signifies the expected improvement through selection.

Table 2: Genetic Parameters of Key Traits

Trait	GCV (%)	PCV (%)	Heritability (%)	GAM (%)
Grain yield	18.3	19.1	87.9	34.6
Productive tillers	12.3	14.1	83.6	22.5
Spikelet fertility	14.8	15.3	92.7	29.4
Biological yield	15.7	16.1	91.2	30.1
Plant height	9.2	10.6	75.3	16.8
Days to 50% flowering	6.4	7.2	80.1	11.9

Interpretation

- Traits such as grain yield, biological yield, and spikelet fertility exhibited high GCV, high heritability, and high GAM, indicating that additive gene action is predominant.
- Traits like days to flowering had relatively lower GCV and PCV but moderate heritability, suggesting moderate selection response.
- Close proximity of PCV and GCV across most traits implies less environmental influence, making phenotypic selection more reliable.

4.3 Correlation Coefficient Analysis

This analysis identifies relationships between traits and helps breeders determine which characteristics indirectly improve yield.

Table 3: Pearson's Correlation Coefficients for Selected Traits

Trait	Grain Yield	Productive Tillers	Spikelet Fertility
Productive Tillers	0.79		
Biological Yield	0.83	0.65	0.68
Spikelet Fertility	0.71	0.59	
Days to Flowering	-0.42	-0.31	-0.26
Plant Height	-0.37	-0.22	-0.18

(= significant at $p < 0.01$, = significant at $p < 0.05$)

Key Takeaways:

Grain yield was positively and significantly correlated with productive tillers, spikelet fertility, and biological yield. Negative correlations with plant height and days to flowering suggest that short, early genotypes are more yield-efficient under the studied conditions.

4.4 Path Coefficient Analysis

To dissect cause-effect relationships, the correlation coefficients were decomposed using path analysis.

Table 4: Path Coefficients (Direct Effects) on Grain Yield

Trait	Direct Effect on Grain Yield
Biological Yield	0.643
Spikelet Fertility	0.438
Productive Tillers	0.392
Panicle Length	0.211
Days to Flowering	-0.158

Interpretation:

- Biological yield had the highest direct positive effect, confirming its central role in yield enhancement.
- Spikelet fertility and tillers contributed substantially both directly and indirectly.
- Traits with high indirect effects via biological yield should be considered for indirect selection.

5. Discussion

The extensive analysis of variance, genetic variability, correlation, and path coefficients reveals several key insights regarding the nature of yield-related traits and their potential utility in breeding.

5.1 Genetic Variability and Trait Expression

The high degree of variability observed for traits such as grain yield, biological yield, and spikelet fertility underscores the rich genetic diversity within the advanced

rice genotypes studied. These results are consistent with earlier findings by Singh *et al.* (2011)^[10] and Basavaraja *et al.* (2013)^[11], who emphasized that variability in spikelet number, tillering capacity, and grain weight serves as a vital resource for trait improvement.

The proximity of GCV and PCV values for most traits further suggests that environmental influence is minimal, indicating the reliability of phenotypic selection. For instance, grain yield exhibited a GCV of 18.3% and PCV of 19.1%, denoting stable genotypic performance across locations.

5.2 Heritability and Genetic Advance: Indicators of Selection Efficiency

Traits such as biological yield (91.2% heritability, 30.1% GAM), spikelet fertility (92.7%, 29.4%), and grain yield (87.9%, 34.6%) showed high heritability and genetic advance, indicating additive gene effects. According to Johnson *et al.* (1955)^[6], such traits are governed largely by fixable genetic factors and thus can be improved effectively through simple selection methods.

In contrast, traits like panicle length and 1000-grain weight, which had moderate heritability and lower GAM, suggest the involvement of non-additive gene actions. These would require breeding strategies like recurrent selection or hybridization followed by selection in segregating generations.

5.3 Trait Associations and Yield Improvement Strategy

The strong positive correlations of yield with productive tillers ($r = 0.79$), biological yield ($r = 0.83$), and spikelet fertility ($r = 0.71$) imply that multi-trait selection will enhance yield gain.

This agrees with Zahid *et al.* (2006)^[11], who reported that yield is a complex polygenic trait, and its improvement is more effective when indirect selection is based on highly associated contributing traits.

The negative correlation with plant height and days to flowering implies that shorter, early-maturing varieties may be more efficient under current environmental stressors such as drought or heat late in the growing season.

5.4 Path Analysis: Decoding Cause-Effect Relations

While correlation analysis indicates associations, path coefficient analysis clarifies causal relationships:

- Biological yield had the highest direct effect (0.643), confirming its status as a major yield component.
- Productive tillers and spikelet fertility also had substantial direct effects, indicating they directly enhance grain yield.
- Panicle length and leaf area index, although showing weak correlation, had significant indirect effects, particularly through biological yield.

These findings are comparable to those of Rathod *et al.* (2020)^[8], who demonstrated the role of biological yield and spikelet fertility in determining rice yield through indirect contribution via harvest index.

6. Breeding Implications and Practical Applications

6.1 Ideotype Development

An ideotype for yield resilience in rice under heterogeneous environments, based on this study, would feature:

- Moderate to high productive tillers (≥ 10 /plant)

- High biological yield
- Greater spikelet fertility
- Short to medium plant stature
- Early to medium flowering (85-95 days)

This ideotype minimizes lodging risks and maximizes resource-use efficiency.

6.2 Selection Strategy Recommendations

Breeding Objective	Recommended Trait(s)	Reason
Yield Improvement	Biological Yield, Tillers	High heritability and direct effect
Stress Tolerance	Early Flowering, Short Height	Associated with yield under drought stress
Efficient Source-Sink Balance	Harvest Index	Improves translocation of assimilates
Wide Adaptability	Spikelet Fertility	Consistent across environments

6.3 Integration with Molecular Breeding

Genotypes identified with high trait stability and performance can be used in marker-assisted selection (MAS) and QTL mapping programs. For example, QTLs linked to productive tillers (e.g., qPT1.1, qPT2.1) or biological yield (qBY4.1) could be targeted in future genomics-assisted breeding.

7. Conclusion

This research demonstrated substantial genetic variability, high heritability, and strong trait associations among advanced rice genotypes evaluated under three contrasting environments. Traits such as biological yield, productive tillers, and spikelet fertility emerged as key contributors to yield, supported by both correlation and path analysis.

The study emphasizes the feasibility of simple phenotypic selection for these traits due to their high additive genetic control. These findings serve as a guiding framework for varietal development and ideotype breeding in rice, contributing to increased productivity and sustainability under climate-affected production systems.

8. Recommendations

1. Select for high biological yield and tillering capacity to drive grain yield gains.
2. Integrate early maturity and short plant stature into breeding pipelines for stress-prone regions.
3. Use high-performing genotypes as parents for hybridization and trait introgression.
4. Validate these genotypes across multiple years and agroecologies to confirm stability.
5. Couple phenotypic screening with molecular marker-based selection for efficiency.

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10. Appendices

A1. List of Genotypes Used in the Study

The following 27 genotypes were selected for the study, comprising both advanced strains and checks:

1. CSR1143
2. CSR1620
3. Kalanamak
4. Pusa Basmati-1
5. Sahi Dawat
6. Damini Delta
7. DRR Dhan-44
8. Pusa-44 (Check)
9. Sarjoo-52 (Check)
10. Basmati 370
11. K-8
12. Pusa 1121
13. Pusa Basmati-2
14. Kusum
15. Hamsa
16. Madhuri
17. Sindhu
18. RNR15048
19. Moti
20. R-19
21. Dhanlakshmi
22. Chhattisgarh Basmati
23. NDR8301
24. NDR9206
25. DRR Dhan-15
26. Suruchi
27. Sabita

A2. Soil and Climate Data

Soil Characteristics:

- Soil pH: Slightly alkaline (8.1-9.5)

- Soil Type: Varies by location (rainfed, saline-sodic, and irrigated soils)

Weather Data

- Maximum Temperature: 34.5 °C
- Minimum Temperature: 12.3 °C
- Rainfall: Up to 168.5 mm/week during crop cycle (June-November)
- Relative Humidity: 62-87%

A3. Statistical Analysis Details

The following methodologies were used to analyze the data:

1. Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV): Burton and de Vane (1953)
2. Heritability (H): Broad-sense heritability calculated according to Hanson *et al.* (1956)
3. Genetic Advance (GA): Calculated using the formula by Robinson *et al.* (1949)
4. Correlation and Path Analysis: Dewey and Lu (1959)
5. ANOVA: Analysis of Variance based on Panse and Sukhatme (1967)^[7]
6. Cluster Analysis: Euclidean non-hierarchical method

A4. ANOVA Summary for Key Traits

The table below presents a summary of the ANOVA results for the measured traits across all genotypes and environments:

Trait	Mean Square (Genotypes)	Significance Level
Days to 50% flowering	95.42	Highly significant
Plant height	127.83	Highly significant
Productive tillers	14.12	Highly significant
Grain yield	78.41	Highly significant
Spikelet fertility	21.35	Highly significant

A5. Genetic Parameters of Key Traits

The table below provides a summary of genetic parameters

Breeding Objective	Recommended Trait(s)	Reason
Yield Improvement	Biological Yield, Tillers	High heritability and direct effect
Stress Tolerance	Early Flowering, Short Height	Associated with yield under drought stress
Efficient Source-Sink Balance	Harvest Index	Improves translocation of assimilates
Wide Adaptability	Spikelet Fertility	Consistent across environments

calculated for key traits:

Trait	GCV (%)	PCV (%)	Heritability (%)	Genetic Advance (GAM, %)
Grain yield	18.3	19.1	87.9	34.6
Productive tillers	12.3	14.1	83.6	22.5
Spikelet fertility	14.8	15.3	92.7	29.4
Biological yield	15.7	16.1	91.2	30.1
Plant height	9.2	10.6	75.3	16.8
Days to 50% flowering	6.4	7.2	80.1	11.9

A6. Correlation Coefficients for Selected Traits

Below are the Pearson's correlation coefficients for selected traits, indicating relationships that may inform breeding decisions:

Trait	Grain Yield	Productive Tillers	Spikelet Fertility
Productive Tillers	0.79		
Biological Yield	0.83	0.65	0.68
Spikelet Fertility	0.71	0.59	
Days to Flowering	-0.42	-0.31	-0.26
Plant Height	-0.37	-0.22	-0.18

A7. Path Coefficients on Grain Yield

The following table presents direct effects of traits on grain yield:

Trait	Direct Effect on Grain Yield
Biological Yield	0.643
Spikelet Fertility	0.438
Productive Tillers	0.392
Panicle Length	0.211
Days to Flowering	-0.158

A8. Breeding Strategy Recommendations

Breeding objectives and the corresponding trait recommendations for enhanced yield and resilience: