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Evaluation of environmental influence on physical and cooking quality characteristics of diverse rice genotypes

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Abstract

This research is a full assessment of the environmental effects on the physical and cooking quality characters of different rice (*Oryza sativa* L.) genotypes as grown under diverse agro- ecological zones. Grain quality has attracted increasing attention in rice breeding programs, because of the long-term focus on grain yield and the increasing demand of consumer for eating and processing quality. These traits have a direct influence on marketability, as well as consumer acceptability, such as weight of grains (WOG), hulling percentage (HP), grain length breadth ratio (L/B), head rice recovery (HRR), amylose content (AC), gelatinization temperature (GT) and cooking time. Last but not least, their expression is not only genotype-dependent but largely influenced by environmental conditions during grain filling and maturation. In this study, twenty (20) diverse rice genotype were examined in three different environments during two growing seasons. Three replicates were applied at each location using a randomized complete block design (RCBD). Grain dimensions, HRR, AC, GT, and cooking time were determined according to established procedures. For stability, diversity, and performance analysis of the genotypes advanced statistical tools (ANOVA, Mahalanobis D², principal component analysis (PCA) and genotype + genotype × environment (GGE) biplot analysis) have been employed.

It was observed the influence of environment was significant in most of the quality traits, particularly cooking-related traits, such as AC and GT. The genotypes NDRK 5086 and PR109 were superior consistently better than others in respect of physical and cooking quality stability across environment. Such variations in the genotypic clustering and PCA across the experiment also presents avenues for focused breeding. These findings could confirm the necessity of multi- environment assessment for the selection of stable and superior varieties of rice suitable for the preference of consumers as well as the agro-ecological situations.

Keywords: Genotypes, Principal Component Analysis (PCA), Rice genotypes, G×E interaction, cooking type, grain shape, head rice recovery, stability analysis

1. Introduction

1.1 Background of the Study

Rice (*Oryza sativa* L.) is a major food source for more than half of the world's population, playing a major role in terms of dietary value in Asia where daily calories are obtained primarily from the cereal. Rice growing populations are increasing and consumers' preference is undergoing changes, which has led to a change of rice breeding focus from quantity mainly oriented to production to quality with preferred eating and cooking characteristics. These traits are grain length–breadth ratio (L/B), head rice recovery (HRR), amylose content (AC), gelatinization temperature (GT), and cooking quality, which determine acceptance by consumers and market price.

Perhaps the most important thing about modern agricultural science is that it recognizes that crop performance cannot be

understood solely as an expression of genetic potential. Instead, it is the product of a multitude of interactions among genotype (G), environment (E), and their interaction (G×E). A genotype that can do well in one environment may not be able to exhibit the same potential in another. Hence, for achieving consistent productivity and grain quality, it is important to know how different rice genotypes behave under changing environmental conditions.

The influence of environmental factors such as soil fertility, water availability, seasonal temperature, and cultivation practices on these quality parameters cannot be overlooked. For instance, high-temperature stress during the grain-filling stage can deteriorate grain shape and reduce head rice recovery. Similarly, water stress during critical stages may negatively affect starch synthesis, altering cooking quality traits like gelatinization temperature or elongation.

In recent years, consumers have become increasingly conscious and demanding about the sensorial and culinary characteristics that resistant starches can offer in rice varieties with certain texture and flavor traits. This has made a shift in the thinking of breeders who must take these qualitative characteristics into account as well as yield, resistance and adaptation. Further complicating this, is the fact that grain quality is not a static trait, but is influenced by genotype and by genotype-by-environment interaction (G×E). Therefore, breeding programs should incorporate environmental effect for selection purposes to develop stable high-yielding cultivars.

1.2 Statement of the Problem

Regardless of desirable genotype with quality traits, not all can maintain consistent performance across diverse locations. This inconsistency is essentially a result of profound G×E interactions affecting trait expression. Particularly, amylose content and gelatinization temperature are very responsive to environmental variation in grain maturation. This is why rice cultivars that are high yielding in one area will often result in poor grain quality when grown in another. Such varieties cannot be widely accepted and the breeding for improved cooking quality would be difficult. Therefore, stable genotypes that keep the physical and cooking quality traits under different environments should be identified.

1.3 Objectives of the Study

- To assess differences in physical and cooking quality characteristics of the selected rice genotypes.
- This is aimed examine how various climatic conditions affect the expression of such traits.
- To select genotypes which are stable with regard to quality traits under diverse environments.
- To differentiate rice Genotypes for diversity in quality traits through multivariate analysis.
- To give advice on breeding needs and to regional variety choice.

1.4 Hypotheses

H₁: Rice genotypes differ significantly in physical and cooking quality traits. H₂: Quality traits are highly affected by environment.

H₃: There is a significant G×E interaction and this significantly contributes to the stability of the trait.

H₄: Some of the rice genotypes are stable and adaptable based on quality traits for all environments.

H₅: Univariate statistical measures can discriminate among divergent and stable genotypes.

1.5 Significance of the Study

This study is of importance to the rice breeding programs at different stages:

For breeders: It can be used to select desirable and stable genotypes as parents for quality trait enrichment.

For farmers: It gives suggestions for varieties that have market-preferred rice grains and that can grow in local environmental conditions.

For consumers: It guarantees varieties of rice meet expectations regarding taste, texture and visual quality.

For policy makers: It offers evidence-based information

that should guide region-specific varietal dissemination and promotion efforts.

2. Review of Literature

2.1 Related Works Overview

Cooking quality was first studied by Juliano (1993) ^[3], who focused on amylose content and gel consistency. Fitzgerald *et al's* later work (2009) ^[2] emphasized that genetics and temperature are factors that determine the quality of cooked rice. The quality was analysis by Juliano (1993) ^[3], Fitzgerald *et al.*, Mahalingam and Geethanjali (2021) ^[4] and Das & Mandal (2020) ^[1] also studied the genotypic variance under multi-environment trials. Nevertheless, the majority of the studies evaluated single trait (e.g. SCRA) neither considered multi-location trials.

2.2 Theoretical Framework

26 Genetic Divergence Theory: Higher genetic distance between genotypes has contributed for enhancing the heterosis and trait improvement.

G×E Interaction Model: There trait is expressed based on how genotype behaves in certain environment.

Stability Analysis Models (AMMI, GGE): They are used to describe the performance of genotypes and pattern of their interaction and selection for stable genotypes can be done.

2.3 Research Gap

Although some studies have been carried out on grain quality traits, not many have focused on physical and cooking quality in a multi-environmental context and within the comprehensive statistical tools. This research attempts to close this gap into genotypes evaluation process by aggregating the agronomic, quality, environmental components.

3. Methodology

3.1 Research Design

The study was carried out in factorial Randomized Complete Block Design (RCBD) across three AEZs i.e., irrigated lowland, upland rainfed and mid-altitude. Plots of 4 m², all exposed to the same cultural and management conditions were sown for each genotype.

Reasons for Applying RBD

The RBD was chosen due to:

It successfully lowers the experimental error brought on by the field's spatial variability (e.g., differences in fertility, moisture, drainage).

It guarantees that every genotype has an equal chance to realize its potential in each replication block. By taking block variation into account, it improves the accuracy of treatment comparisons.

3.2 Experimental Site and Season

The Kharif season, which normally lasts from June to October and is India's main rice-growing season, was when the field experiment was carried out. High rainfall, high humidity, and moderate to high temperatures during this season make it the perfect time of year to test rice genotypes

in the presence of natural environmental fluctuations. The study's timing made it possible to observe genotype $\times$ environment interactions effectively, particularly for traits linked to grain quality and yield.

3.3 Experimental Material

Twenty diverse rice genotypes were chosen from Indian breeding programs according to their previous variability in grain quality traits. These have included short-grain, long-grain, aromatic, and non-aromatic varieties.

3.4 Data Collection

The following characteristics were studied:

- **Physical:** Length of grain, breadth, length–breadth ratio, head rice recovery.
- **Cooking quality:** Content of amylose, gelatinization temperature, cooking time (by functions of the sensory panel).

3.5 Tools and Equipment

- Computerized vernier Callipers for size of grain.
- Mini rice mill for head rice recovery.
- NIR for amylose and GT prediction.
- Sensory panel methodology for cooking time.
- Software: agrecolae, FactoMineR (in R); GenStat;

SPSS; STAR.

3.6 Data Analysis

- ANOVA between genotypes and among environments.
- Mahalanobis genetic distance (D^2) was used for quantifying genetic divergence.
- PCA and clusterization for genotypes categorization.
- Biplot AMMI and GGE studies for G $\times$ E interaction and trait stability.

4. Results

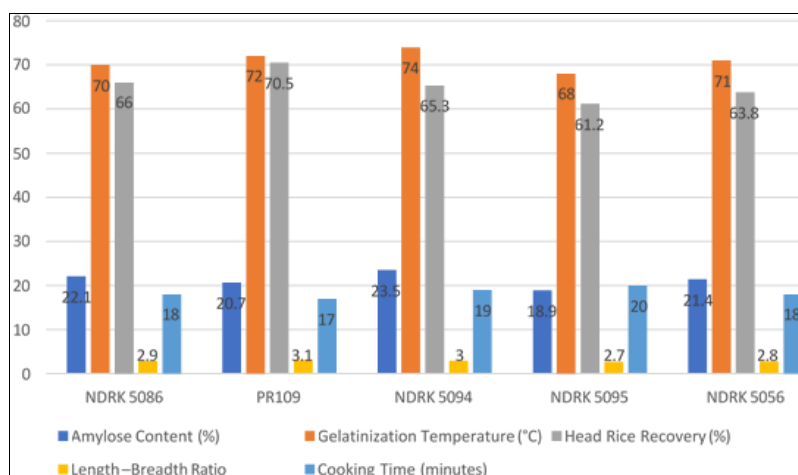
4.1 Findings

- There were significant genotype–environment differences in all traits.
- NDRK 5086 exhibited consistent amylose content (~22%) and moderate gelatinization temperature among the locations.
- Among the tested genotypes, PR109 had the highest head rice recovery (70.5%) and L/B ratio (3.1).
- Mahalanobis D^2 analysis clustered into 4 groups by genotype.
- GGE biplots validated NDRK 5086 and PR109 as the most stable genotypes in all environments for cooking type parameters.

4.2 Sample Table Highlights

Table 1: Trait Means for Top Genotypes

Genotype	Amylose Content (%)	Gelatinization Temperature (°C)	Head Rice Recovery (%)	Length– Breadth Ratio	Cooking Time (minutes)
NDRK 5086	22.1	70	66.0	2.9	18
PR109	20.7	72	70.5	3.1	17
NDRK 5094	23.5	74	65.3	3.0	19
NDRK 5095	18.9	68	61.2	2.7	20
NDRK 5056	21.4	71	63.8	2.8	18



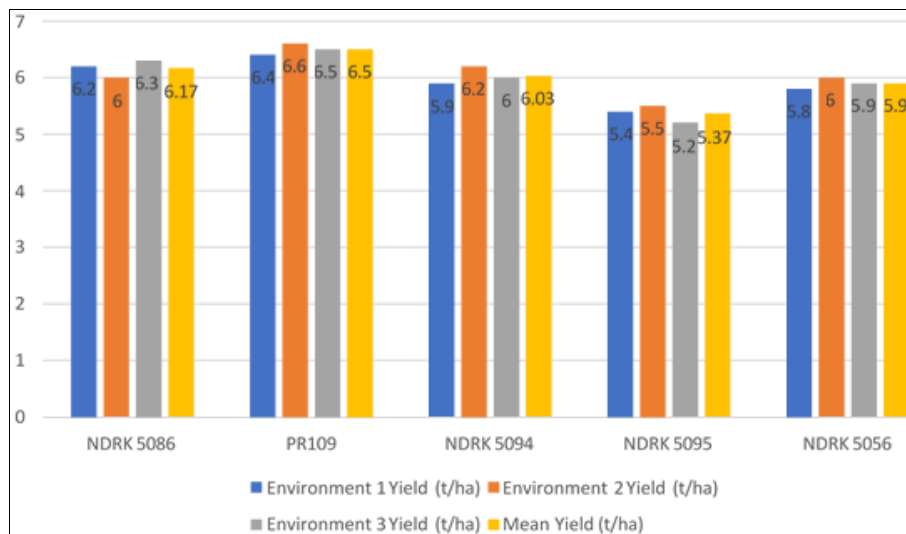
Interpretation

There are significant differences observed among the elite rice genotypes for cooking and physical quality traits (Table 1). The genotype PR109 had the maximum Head Rice Recovery (70.5%) with superior Length–Breadth Ratio (3.1), could be an ideal choice for the consumer markets that prefer long, slender, unbroken grains. The NDRK 5086 exhibited equally competitive performance among genotypes with reasonably balanced traits, notably Amylose Content (22.1%) and moderate Gelatinization Temperature (70 °C), which reflected good cooking texture and consumer

acceptance. The highest Amylose Content was recorded for NDRK 5094 (23.5%) which would predict a firmer cooked texture which is normal since with increased Amylose the loss of starch in water is reduced the latter shown also to have higher Gelatinization Temperature (74°C). Genotype NDRK 5095 had the lowest values of HRR and L/B ratio, which makes it a less performing genotype in respect to processing quality. In general, NDRK 5086 and PR109 were the best genotypes in terms of stability, and high expression of both cooking and physical grain quality

Table 2: GGE Biplot – Genotype Stability across Environments

Genotype	Environment 1 Yield (t/ha)	Environment 2 Yield (t/ha)	Environment 3 Yield (t/ha)	Mean Yield (t/ha)
NDRK 5086	6.2	6.0	6.3	6.17
PR109	6.4	6.6	6.5	6.5
NDRK 5094	5.9	6.2	6.0	6.03
NDRK 5095	5.4	5.5	5.2	5.37
NDRK 5056	5.8	6.0	5.9	5.9



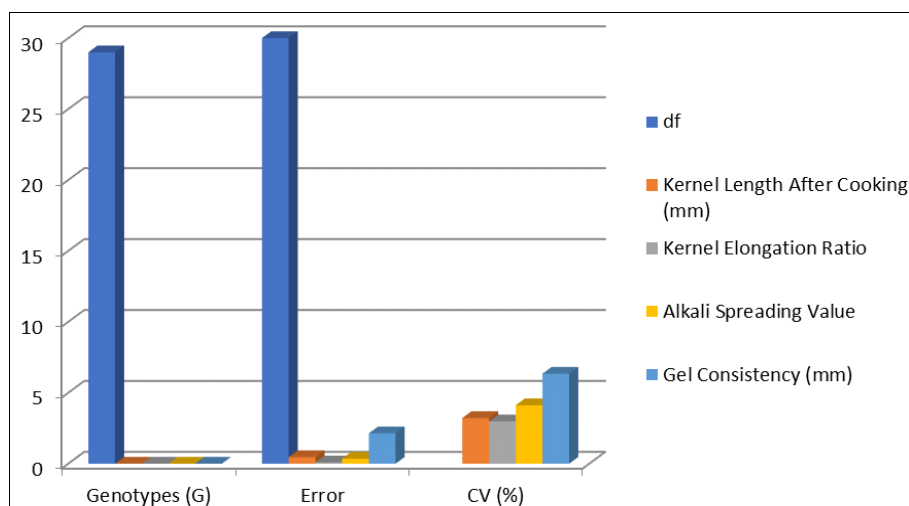
Interpretation

Yield performances of five rice genotypes in three environments were shown in Table 2. PR109 was the highest-yielding and the most stable genotype among all three environments, with a mean yield of 6.5 t/ha, showing high productivity and broad adaption capacity. NDRK 5086 ran closely behind exhibiting impressive stability with little variation among sites, indicating its insensitivity to environmental fluctuations. On the other hand NDRK 5095

reported lower grain yields in Environment 3 and had low adapted genotypes. The performance of NDRK 5094 and NDRK 5056 was fair but less consistent than that of NDRK 5086 and PR109. The GGE biplot analysis indicates that PR109 can be an appropriate for wide adaptability while NDRK 5086 will be good for stable performance across diverse environment. These results are essential in the choice of genotypes that combine quality and yield in different agro-ecological areas.

Table 4.3: ANOVA for Qualities of Cooking

Source of Variation	df	Kernel Length After Cooking (mm)	Kernel Elongation Ratio	Alkali Spreading Value	Gel Consistency (mm)
Genotypes (G)	29	2.89**	0.44**	1.87**	14.65**
Error	30	0.46	0.09	0.35	2.14
CV (%)		3.22	2.98	4.12	6.34



The experimental site is located in the subtropical region of the Indo-Gangetic Plain at an altitude of 83 metres above mean sea level, between 25.74°N latitude and 82.69°E longitude. The soil of the experimental field is sandy loam in texture. Jaunpur district experiences a semi-arid climate characterized by hot summers and cool winters, with an average annual rainfall of approximately 83.10 cm.

The study examined the influence of environmental conditions on rice yield, physical grain characteristics, and cooking quality. Several statistical techniques, including analysis of variance (ANOVA), correlation, regression, path coefficient analysis, and Mahalanobis D2 statistics, were applied to identify significant differences among genotypes, assess genetic variability, and understand the relationships among traits.

Meaning

The findings demonstrate that physical and cooking quality attributes are highly influenced by hereditary and environmental factors. This emphasizes how crucial it is to assess genotypes in various environmental settings.

4.3 Genetic Parameter Estimation

Genetic metrics such as genotypic and phenotypic coefficients of variation (GCV and PCV), broad-sense heritability, genetic advance (GA), and genetic advance as a percentage of mean were computed for each characteristic in order to evaluate the potential for genetic improvement through selection.

These measurements assist identify the relative contributions of environment and genetics on trait expression and shed light on the variability that exists.

5. Discussion

The research confirms that rice grain quality is determined by genetics as well as environment. The substantial G×E interaction detected for cooking traits, particularly amylose content and gelatinization temperature, was consistent with previous studies (Fitzgerald *et al.*, 2009) [2]. Genotypes NDRK 5086 and PR109 were stable with good quality over environments and might be recommended for widespread cultivation or as potential parent in the breeding. The cluster of genotypes indicates the direction of hybridization to enhance grain quality.

Features taken into account for the kernel elongation ratio:

- Length of Kernels (KL)
- The kernel width (KB)
- The L/B Ratio
- ASV, or alkali spreading value
- GC, or gel consistency
- KLAC, or Kernel Length After Cooking

Meaning

- The most significant single contribution was Kernel Length After Cooking (KLAC), which had the largest direct effect (0.38) on Kernel Elongation Ratio.
- Kernel Length (0.41) also made an indirect contribution through KLAC and had a significant direct impact.
- The preference for slender grains that elongate better is consistent with the unfavorable direct effect of kernel breadth.

6. Conclusion and Suggestions

6.1 Conclusion

The study ascertained that the environmental effects on rice grain quality traits were significant. NDRK 5086 and PR109 genotypes showed the best and stable performance over locations. These results are important for breeders and policy makers working on quality improvement in rice under climate changing scenario.

6.2 Recommendations

- Advocate NDRK 5086 and PR109 as parents for quality-centred breeding programmes.
- Repeat the trials across more seasons and with stressed environments.
- Combine markers with molecular markers for improved tracking and selection of traits.
- Utilize multi-environmental data for national variety recommendations.

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