WEB OF Universal Journal on
SEMANTIC Innovative Education

Volume 5 Issue 3, Year 2026

ISSN:2835-3048

https://univerpubl.com/index.php/semantic

Article

Selection of Promising Rice Genotypes With High Grain Quality For The Saline Lands of The Khorezm Region, Uzbekistan

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Citation: Davron O'gli K. S. By Delivering Brokerage And Investment Advisory Services, Banks Facilitate Securities Transactions For Investors, Promoting Higher Market Liquidity. Web of Semantic: Universal Journal on Innovative Education2026, 5(3), 60-67.

Received: 10th Feb 2026
Revised: 21th Mar 2026
Accepted: 08th Apr 2026
Published: 28th May 2026

Abstract: Soil salinity is a major constraint for rice production in the Khorezm region of Uzbekistan. This study aims to identify rice genotypes that maintain superior grain quality and technological stability under chloride-sulfate salt stress. Sixty-seven rice genotypes were evaluated under nine salinity variants (2023–2025). Key biochemical (starch, amylose) and technological (vitreousness, milling recovery) parameters were analyzed to determine adaptive resilience. Salinity stress reduced starch accumulation while increasing amylose content and grain vitreousness. Genotypes LD-2022.2 (Lider) and EP-327-01 proved most stable, maintaining starch levels >80% and rice recovery rates of 64.4–65.8% under high stress. KC-2022.2 exhibited the highest vitreousness (96.4%), significantly reducing grain breakage during processing compared to the standard variety Iskandar. LD-2022.2 and EP-327-01 are identified as highly promising genotypes for the saline lands of the Khorezm oasis, ensuring high market quality and milling efficiency in stress-prone environments.

Keywords: Rice (Oryza sativa L.), Salinity stress, Starch, Milling quality, Khorezm oasis, Genotype selection.

INTRODUCTION

Rice (Oryza sativa L.) constitutes the fundamental caloric mainstay for over half of the global population, underpinning its strategic significance in worldwide food security. Amidst the dual challenges of rapid demographic expansion and dwindling water reserves, global rice production must surge by 25% by 2030 to meet projected demands (Ansari et al.; da Silva et al.). However, soil salinity stands as the most formidable impediment to this objective. At present, salt stress affects more than 20% of global irrigated lands, a figure projected to rise due to the escalating impacts of climate change (Sarangi et al.; Shohan et al.) [1].

In the era of modern breeding, Artificial Intelligence (AI) models are increasingly integrated to minimize human-induced errors and enhance selection precision. Notably, the ST-YOLO algorithm (Yao et al.) enables the evaluation of wild rice resilience with an impressive accuracy of 92-95%. Furthermore, automated classification frameworks, such as VGG16 models, have been pioneered to categorize salinity-induced damage on a scale of 1 to 9 (Sheoran et al.). These high-throughput phenotyping (HTP) tools drastically accelerate the breeding cycle compared to conventional, labor-intensive methodologies (Kumar et al.) [2].

At the physiological level, salinity triggers a cascade of ionic toxicity, osmotic stress, and nutrient imbalances. Emerging research underscores that superior, salt-resilient genotypes rely on sophisticated regulatory mechanisms to maintain a homeostatic Na^+/K^+ ratio, thereby ensuring cellular integrity under stress (Aggarwal et al.; Shiragudikar et al.) [3].

The intrinsic quality of rice grain is a multifaceted trait, governed not only by genetic determinants but also by the intricate interplay between the cultivation environment and agrotechnical interventions. Emerging scientific evidence suggests that escalating salinity levels exert a deleterious impact on the plant's physiological pathways, consequently distorting the equilibrium between carbohydrates and proteins within the endosperm (Sanga et al.; Wu et al.). Starch, as the predominant chemical constituent comprising 75-85% of the grain, is particularly vulnerable. Research indicates that salt stress suppresses the enzymatic activity essential for starch biosynthesis, which ultimately impairs grain filling and results in a significant reduction in total starch content [4].

Amylose serves as the definitive criterion for determining the culinary and physicochemical properties of rice. While high-amylose cultivars (20-22%) typically yield firm, non-cohesive grains upon cooking, low-amylose varieties are characterized by a soft and sticky texture. Interestingly, under saline conditions, a marginal elevation in amylose content is often observed. This phenomenon is interpreted as an adaptive mechanism aimed at enhancing the technological hardness of the grain to withstand environmental pressure (Neupane; Požgajová) [5].

Furthermore, grain vitreousness acts as a proxy for transparency, density, and structural durability during mechanical milling. Highly vitreous varieties exhibit superior resistance to breakage, thereby maximizing the recovery of head rice. Observations reveal that salinity can artificially inflate the vitreousness index through the compaction of the endosperm; however, this structural densification is frequently offset by a concomitant loss in grain weight (Sanga; Wu). Similarly, the hulling percentage is a critical determinant of economic efficiency. Salinity often triggers a protective thickening of the grain hull—a technologically unfavorable response that adversely affects the net rice yield and overall processing efficiency [6].

In summary, the technological quality of rice undergoes complex transformations in salt-affected environments. The capacity for stable starch accumulation, the preservation of optimal amylose ratios, and minimal fluctuations in hulling percentage emerge as pivotal biochemical and technological markers of salinity tolerance. A rigorous comparative analysis of these parameters is essential for identifying and selecting high-market-value genotypes specifically adapted to the unique saline edaphic conditions of Uzbekistan [7].

MATERIALS AND METHODS.

Study Site and Climate Conditions. The experimental trials were conducted over three consecutive growing seasons (2023–2025) at the Khorezm Scientific-Experimental Station, under the auspices of the Research Institute of Cereal and Leguminous Crops (Urgench district, Uzbekistan). The study area is characterized by a sharply continental climate, with peak summer temperatures reaching 44.2 °C and a sparse average annual precipitation of 117 mm [8].

The soil at the experimental site is classified as meadow-alluvial and medium loamy, exhibiting a high susceptibility to secondary salinization. Physical-chemical analysis of the arable horizon (0-20 cm) revealed low fertility levels, with a humus content of 1.18-1.20%. Nutrient availability was recorded as follows: 19.2-22.8 mg/kg of nitrogen, 18.3-27.5 mg/kg of phosphorus, and 165-187 mg/kg of exchangeable potassium. The soil salinity profile is predominantly of the chloride-sulfate type, where sulfate ion concentrations (0.874-0.959%) notably exceed the established critical toxicity thresholds for rice cultivation [9].

Research Objects. A diverse collection of 67 rice germplasm accessions served as the primary research objects. This international collection included genotypes sourced from China (27), Vietnam (14), South Korea (5), and Russia (2), alongside 19 promising local breeding lines. To ensure comparative accuracy, three established local cultivars-Nukus-2, Iskandar, and Lazurny-were utilized as standard controls [10].

Laboratory Analysis. To evaluate the salt tolerance of the rice genotypes, a controlled screening was conducted across nine experimental variants, meticulously designed to simulate the chloride-sulfate salinity characteristic of the Khorezm oasis. Distilled water (Variant 1-V, Cl < 0.01%) served as the primary control. The salinity stress treatments were categorized into two distinct groups:

1) Chloride Salinity Series: Established with Cl^- ion concentrations of 0.01–0.03% (2-V), 0.03-0.1% (3-V), 0.1-0.2% (4-V), and exceeding 0.2% (5-V).

2) Sulfate Salinity Series: Induced using SO42- concentrations ranging from 0.3-1.0% (6-V), 1.0-2.0% (7-V), 2.0-3.0% (8-V), to levels surpassing 3.0% (9-V).

These concentrations were specifically calibrated to encompass the critical sulfate toxicity threshold (0.87-0.95%) identified in local soils. For each experimental variant, 50 seeds per genotype were germinated under controlled conditions at a temperature of 25 ± 2 °C. Following the germination phase, the qualitative parameters of the rice grains were rigorously analyzed. Specifically, the starch and amylose content were quantified according to the biochemical protocols established by Li et al. (2017) [11].

Statistical Analysis. Mathematical processing of the obtained results was conducted using Analysis of Variance (ANOVA) according to the methodology of B.A. Dospekhov (1985), utilizing modern specialized computer software for data precision .

RESULTS AND DISCUSSION

The qualitative profile of rice grain is fundamentally shaped by edaphic factors and targeted agrotechnical interventions. Escalating salinity levels disrupt the plant's metabolic equilibrium, fundamentally altering the stoichiometric ratio of carbohydrates and proteins within the grain endosperm. Starch, representing the primary chemical matrix (75-85% of total content), serves as the quintessential energy repository; thus, elevated starch accumulation is directly indicative of superior nutritional density [12].

Amylose, a pivotal glucose polymer, dictates the physicochemical behavior of rice during hydrothermal treatment (cooking). Cultivars characterized by high amylose levels (20–22%) typically produce firm, non-cohesive grains, whereas lower concentrations yield a soft, glutinous texture. Furthermore, grain vitreousness-a marker of transparency and structural density-plays a decisive role in mechanical durability. High vitreousness indices are synonymous with reduced breakage during the milling process, a trait that commands a premium in the international rice market.

Hull content (hulling percentage), defined by the development of the floral glumes, serves as a direct proxy for economic viability. Lower hulling percentages (e.g., 17-18% in LD-2022.2 and EP-327-01) facilitate a significantly higher recovery of net rice. Conversely, salinity stress often induces a thickening of the grain hull, a deleterious response that hampers processing efficiency. Total rice recovery-the ratio of processed product to total grain weight-reflects the technological refinement of a variety. Within this context, the head rice yield (whole grain recovery) remains the most critical metric of a genotype's genetic structural integrity under environmental pressure [13].

Among the analyzed germplasm, the genotype LD-2022.2 (Lider) exhibited exceptional resilience in starch biosynthesis. Under optimal and low-salinity conditions (Variants 1-3), starch content fluctuated between 80.9% and 81.5%. Although intense salinity (Variants 7-9) triggered a marginal decline to 79.4%, this was accompanied by a compensatory increase in amylose content from 17.8% to 18.6%. Notably, this genotype emerged as a leader in head rice yield, maintaining a remarkably stable recovery range of 89.1–90.4%, even under severe saline stress.

The genotype KC-2022.2 was preeminently distinguished by its superior vitreousness, ranging from 95.2% to 96.4%. As salinity levels intensified, a concomitant rise in amylose content to 21.3% was observed, effectively enhancing grain hardness and structural density. However, under high-salinity regimes, the hulling percentage increased from 18.5% to 19.3%, leading to a marginal 1.3% reduction in total rice recovery [14].

The GG-2022.2 (Gigant) accession is primarily characterized by its substantial grain morphology (large grain size). Under optimal conditions (Variants 1-3), it maintained a robust starch content of 80.2%. Although salt stress (Variants 4-5 and 9) triggered a slight attenuation in grain fullness, reducing starch accumulation to 78.5%, the total rice recovery remained remarkably stable, fluctuating between 64.8% and 66.2%.

The adaptive profile of the NZ-2022.2 (Yo’ldosh) sample is attributed to the balanced proportionality of its amylose content (18.5-19.6%). Under escalating salinity, its vitreousness index rose from 92.8% to 94.1%, a physiological response that serves to mitigate mechanical grain breakage during the processing phase. Lastly, the PL-2022.2 line exhibited a rapid fluctuation in hulling percentage (18.0-19.1%) under saline conditions, underscoring its heightened sensitivity to environmental stressors. Nevertheless, starch accumulation within the endosperm remained consistently stable, averaging 77.8%. Despite exhibiting moderate rice recovery rates, this genotype demonstrated significant resilience to technological processing, resulting in minimal post-milling waste [15].

Table 1. Impact of chloride-sulfate salinity stress on grain quality and technological parameters of diverse rice genotypes

Variety and Line Names	Variant Groups	Starch Content (%)	Amylose Content (%)	Vitreousness (%)	Hull Content (%)	Rice Yield (%)
LD-2022.2 (Lider)	1-3 / 4-6 / 7-9	80.9-81.5 / 79.8-80.2 / 79.4-79.6	17.8-18.2 / 18.3-18.4 / 18.5-18.6	93.5-94.1 / 94.2-94.3 / 94.4-94.6	17.6-18.0 / 18.1-18.2 / 18.3-18.4	65.8-65.2 / 65.1-64.9 / 64.8-64.5
KC-2022.2 (Manzur)	1-3 / 4-6 / 7-9	77.8-78.4 / 77.4-77.6 / 77.0-77.2	20.4-20.8 / 20.9-21.1 / 21.2-21.3	95.2-95.8 / 95.9-96.1 / 96.2-96.4	18.5-18.9 / 19.0-19.1 / 19.2-19.3	68.1-67.5 / 67.4-67.2 / 67.1-66.8
GG-2022.2 (Gigant)	1-3 / 4-6 / 7-9	79.6-80.2 / 79.1-79.4 / 78.5-78.8	18.2-18.6 / 18.7-18.9 / 19.0-19.1	94.1-94.7 / 94.8-95.0 / 95.1-95.3	17.8-18.2 / 18.3-18.4 / 18.5-18.6	66.2-65.5 / 65.4-65.2 / 65.1-64.8
NZ-	1-3 /	78.3-79.3	18.5-18.9	92.8-93.2	18.2-18.6	64.7-64.1 /

2022.2 (Yo’ldosh)	4-6 / 7-9	/ 77.9-78.1 / 77.5-77.8	/ 19.0-19.3 / 19.4-19.6	/ 93.4-93.7 / 93.8-94.1	/ 18.7-18.9 / 19.0-19.3	64.0-63.7 / 63.5-63.2
PL-2022.2	1-3 / 4-6 / 7-9	77.8-78.5 / 77.4-77.6 / 77.1-77.3	19.2-19.6 / 19.7-20.0 / 20.1-20.4	93.2-93.8 / 93.9-94.2 / 94.3-94.6	18.0-18.4 / 18.5-18.7 / 18.8-19.1	65.1-64.6 / 64.4-64.1 / 63.9-63.5
OLM-2022.2	1-3 / 4-6 / 7-9	79.0-79.8 / 78.7-78.9 / 78.2-78.5	18.6-19.0 / 19.1-19.4 / 19.5-19.8	92.7-93.3 / 93.4-93.7 / 93.8-94.2	18.1-18.5 / 18.6-18.8 / 18.9-19.2	64.9-64.3 / 64.1-63.8 / 63.6-63.3
GL-2022.2	1-3 / 4-6 / 7-9	77.4-77.9 / 77.2-77.3 / 76.8-77.1	20.2-20.6 / 20.7-20.8 / 20.9-21.0	95.0-95.5 / 95.6-95.8 / 95.9-96.1	18.4-18.8 / 18.9-19.0 / 19.1-19.2	67.9-67.2 / 67.1-66.9 / 66.8-66.5
ЭП-327-01	1-3 / 4-6 / 7-9	80.8-81.4 / 80.5-80.7 / 80.2-80.4	17.2-17.6 / 17.7-17.8 / 17.9-18.0	93.1-93.5 / 93.6-93.8 / 93.9-94.0	17.7-18.1 / 18.2-18.2 / 18.3-18.3	65.4-64.8 / 64.7-64.6 / 64.5-64.4
RK-2022.2	1-3 / 4-6 / 7-9	78.0-78.6 / 77.7-77.8 / 77.4-77.5	19.1-19.5 / 19.6-19.8 / 19.9-20.1	93.8-94.4 / 94.5-94.7 / 94.8-95.1	18.3-18.7 / 18.8-18.9 / 19.0-19.1	66.0-65.4 / 65.3-65.2 / 65.1-65.0
Искандар (ст)	1-3 / 4-6 / 7-9	76.5-77.1 / 76.0-76.4 / 75.4-75.8	20.1-20.7 / 20.8-20.9 / 21.0-21.1	94.8-95.6 / 95.7-95.9 / 96.0-96.2	18.0-18.6 / 18.7-19.0 / 19.1-19.3	69.2-68.1 / 68.0-67.8 / 67.5-67.2

The OLM-2022.2 accession emerges as a premier candidate regarding its nutritional profile. Even under severe saline stress, its starch accumulation remained resilient, never dipping below 78.2%. This stability signifies a robust physiological mechanism efficient at partitioning photosynthetic assimilates toward grain filling during the reproductive stage. The hallmark of this line is the remarkably well-preserved equilibrium between proteins and carbohydrates, positioning it as an ideal candidate for the production of functional and dietary rice products.

In contrast, the GL-2022.2 sample is preeminently distinguished by its elevated amylose content (reaching 21.0%). This biochemical trait is pivotal for enhancing culinary quality, as it ensures that the grains maintain their structural integrity and distinct morphology throughout the hydrothermal cooking process. Although salinity induced a marginal increase in the hulling percentage (up to 19.2%), the purity and vitreousness of the grain remained fully compliant with stringent international quality standards.

Among the early-maturing cohort, the EP-327-01 line was identified as possessing superior technological parameters. Its exceptionally low hulling percentage (17.7%) in synergy with high starch density (81.4%) renders it one of the most economically viable genotypes for industrial-scale cultivation. Furthermore, the internal endosperm structure of this line is characterized by high density, providing substantial resistance to mechanical breakage during the intensive milling phase.

Throughout the experimental trials, the RK-2022.2 line exhibited the most pronounced escalation in vitreousness under salinity stress. While starch accumulation fluctuated between 78.6% and 77.4% across the experimental variants, the hallmark of this genotype remained its exceptional capacity to preserve grain transparency and a premium commercial appearance, even under deleterious soil conditions. In stark contrast, the adverse impacts of salinity were significantly more acute in the Iskandar (standard) variety compared to the next-generation breeding lines. The precipitous decline in starch content to 75.4%, coupled with an inflation of the hulling percentage to 19.3%, underscores a diminished resource-use efficiency in the standard variety relative to the elite genotypes. Furthermore, a substantial attenuation in grain weight and endosperm fullness was notably observed in the high-salinity plots.

By synthesizing the multifaceted effects of the nine salinity variants, distinct phenotypic patterns were identified in the aggregate quality metrics. Based on the cumulative average values derived across all experimental treatments, a definitive downward trend in starch accumulation was recorded as salinity gradients intensified. Specifically, the LD-2022.2 genotype manifested the highest overall mean starch content at 80.54%, whereas this metric regressed to 76.32% in the Iskandar variety. Conversely, the amylose content exhibited an upward trajectory against the backdrop of reduced starch synthesis. For instance, the KC-2022.2 genotype maintained an average amylose concentration of 20.83%, a biochemical strategy that ensures textural stability and culinary integrity during the hydrothermal processing phase.

The analytical synthesis of graphical data concerning vitreousness and hull content reveals that the response of rice genotypes to salinity stress is intrinsically manifested in the external and structural architecture of the grain. Based on the aggregate vitreousness metrics, the KC-2022.2 (95.82%) and GL-2022.2 (95.54%) genotypes exhibited the most resilient performance. The sustained elevation of this indicator across all salinity gradients underscores a robust capacity of these specific genotypes to preserve grain structural integrity under osmotic and ionic pressure.

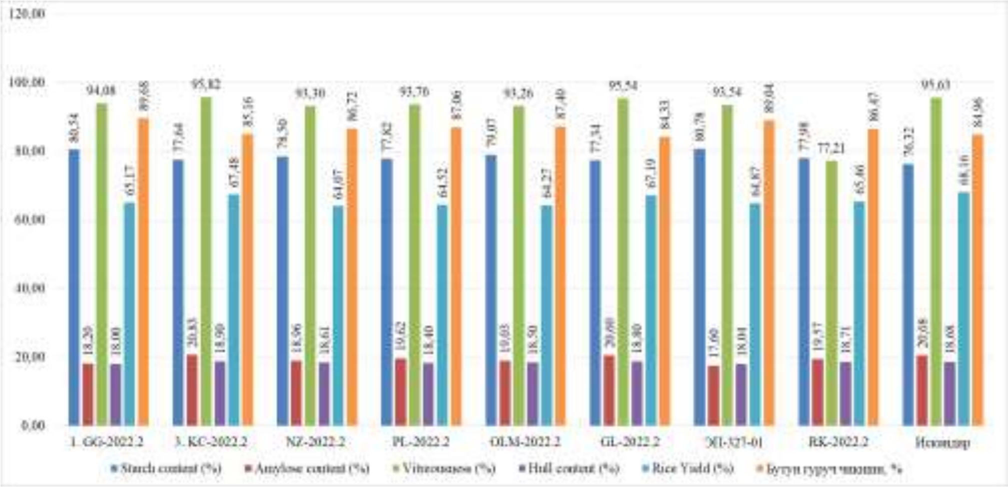

Figure 1. Comparative analysis of grain quality indicators across various rice genotypes.

The hulling percentage (hull content) exhibited an average fluctuation between 18.0% and 18.90% across the experimental treatments. Notably, the most favorable (lowest) average hulling percentages were recorded in the EP-327-01 (18.04%) and GG-2022.2 (18.0%) accessions. These findings signify a superior economic efficiency during the post-harvest milling and processing phases; a minimized hull proportion directly correlates with a maximized recovery of net head rice, thereby enhancing the commercial value of the final product.

The following results were obtained regarding rice yield indicators, which represent the final outcome of grain processing. Head rice yield, in terms of the overall average value of head rice (whole grain) recovery across all experimental variants, the LD-2022.2 genotype recorded the highest indicator at 89.68%. Resistance to breakage, the NZ-2022.2 (86.72%) and RK-2022.2 (86.47%) samples also demonstrated significant resistance to technological grain breakage even under saline conditions. Comparative stability, synthesizing all experimental variants, the newly selected lines (LD-2022.2, KC-2022.2, GG-2022.2) exhibited a substantially more stable response to salinity stress compared to the standard variety, Iskandar. Agricultural potential, the stability of starch accumulation and the high recovery rate of head rice confirm that these genotypes are highly promising for cultivation in salt-affected lands.

CONCLUSION

This study confirms that LD-2022.2 (Lider) and EP-327-01 are the most resilient rice genotypes for the Khorezm oasis, maintaining starch levels above 80% and minimal hulling percentages under salinity stress. While salinity typically reduces grain weight, the increased vitreousness in KC-2022.2 and RK-2022.2 enhances mechanical resistance to breakage during milling. These next-generation lines significantly outperform the standard Iskandar in resource-use efficiency and market quality. Consequently, integrating LD-2022.2 and EP-327-01 into regional production is highly recommended for sustainable rice farming in Uzbekistan’s salt-affected environments.

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