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Effect of water stress regimes on cooking quality characteristics and starch properties of selected rice genotypes

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Abstract

Rice breeders have long selected for yield under water-limited conditions, but the question of whether water stress also alters grain cooking quality has received surprisingly little attention. This research investigated the effect of three water regimes well-watered (W1), moderate stress at panicle initiation (W2), and severe stress at heading (W3) on cooking quality parameters and starch properties of five rice genotypes (IR64, Basmati-370, Swarna, MTU-1010, Pusa-44) grown during the 2022 wet season at ETH Zurich's greenhouse facility. Results showed that water stress significantly altered amylose content (+2.4-4.8 percentage points), gelatinization temperature (+1.7-3.6 °C), and cooking time (+1.8-3.4 min) across genotypes. Basmati-370 maintained the highest cooking quality score under all regimes (7.4-6.3 out of 10), while Swarna was most affected, dropping from 5.9 to 4.8. Water absorption ratio decreased by 8-17% under severe stress. Rapid Visco Analyser (RVA) pasting profiles revealed increased peak viscosity and setback under stress, indicating altered starch granule organization. These findings demonstrate that water management during reproductive growth directly influences end-use quality, with implications for irrigation scheduling in quality-conscious rice markets.

Keywords: Rice, cooking quality, water stress, amylose content, gelatinization temperature, starch properties, RVA pasting, basmati, grain quality, water management

Introduction

A farmer in the Basmati belt of South Asia might produce a record yield in a drought year only to discover at the market that buyers reject the grain because of poor cooking quality. This scenario is becoming more common as water scarcity forces rice growers to adopt deficit irrigation strategies without understanding how reduced water supply during critical growth stages affects the physicochemical properties that consumers value most ^[1]. Cooking quality in rice is determined primarily by three starch characteristics: amylose content (which controls firmness and stickiness), gelatinization temperature (which determines cooking time and energy requirement), and gel consistency (which predicts texture after cooling) ^[2].

These properties are strongly influenced by genetics, but environmental conditions during grain filling particularly temperature and moisture can modify starch biosynthesis enough to shift grain quality from one market class to another ^[3]. Water stress during flowering and grain filling alters the activity of key enzymes in the starch biosynthetic pathway, including Granule-Bound Starch Synthase (GBSS) and Starch Branching Enzyme (SBE), potentially increasing amylose content and changing the ratio of long to short amylopectin chains ^[4]. Despite this mechanistic understanding, few controlled experiments have quantified the magnitude and genotype-specificity of stress-induced quality changes across diverse rice types ^[5, 6].

Theoretical background

Starch in rice grain consists of two glucose polymers: amylose (linear, 20-30% of total starch in non-waxy rice) and amylopectin (highly branched, 70-80%). The relative proportion determines cooking behaviour high-amylose rice cooks firm and dry, while low-amylose rice is soft and sticky ^[2]. GBSS, encoded by the Wx gene, synthesizes amylose within the starch granule.

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Water deficit during grain filling has been shown to upregulate GBSS expression in some genotypes, increasing amylose by 2-5 percentage points [4]. Gelatinization temperature the point at which starch granules irreversibly swell in hot water is controlled by amylopectin chain length distribution and measured by Differential Scanning Calorimetry (DSC) or the alkali spreading test [7]. The RVA pasting profile provides a functional measure of starch behaviour during heating and cooling, with peak viscosity reflecting granule swelling capacity and setback indicating retrogradation tendency [8].

Materials and Methods

Materials

The experiment was conducted from June to November 2022 in the controlled-environment greenhouse of the Department of Food Science, ETH Zurich, Switzerland (47°22'N, 8°33'E). Five indica rice genotypes representing diverse quality classes were grown in 15 L pots filled with puddled paddy soil sourced from IRRI's soil bank. Genotypes included: IR64 (intermediate amylose, widely grown), Basmati-370 (high amylose, premium aromatic), Swarna (intermediate amylose, high-yielding), MTU-

1010 (intermediate amylose, early maturing), and Pusa-44 (high amylose, long-grain). Three water regimes were imposed: W1 (continuous flooding at 5 cm depth), W2 (stress at panicle initiation water withheld for 7 days when soil moisture reached -30 kPa), and W3 (stress at heading water withheld for 10 days at -50 kPa). The experiment followed a factorial CRD with 5 genotypes × 3 water regimes × 4 replications (60 pots) [9].

Methods

Harvested grain was dehusked, milled to white rice (mill recovery 68-72%), and analysed for: amylose content (iodine colorimetric method, ISO 6647), gelatinization temperature (DSC, TA Instruments Q200), gel consistency (tube test method), water absorption ratio (WAR, mass gain after 30 min soaking at 20 °C), cooking time (minimum time for gelatinization of 90% of grains), and overall cooking quality score (sensory panel, 10-point hedonic scale, 8 trained panelists). RVA pasting profiles were obtained using a Newport Scientific RVA-4 with the standard AACC Method 61-02. Data were analysed by two-way ANOVA (genotype × water regime) with Tukey's HSD at $p < 0.05$ [10, 11].

Results

Table 1: Effect of water regime on cooking quality parameters of five rice genotypes

Genotype	Water regime	Amylose (%)	GT (°C)	Cook time (min)	WAR	Quality score
IR64	W1	23.4	71.2	18.3	2.64	6.8
	W2	25.1	72.4	19.6	2.47	6.4
	W3	27.8	74.3	21.7	2.28	5.7
Basmati-370	W1	26.7	68.4	16.1	3.12	7.4
	W2	28.3	69.8	17.4	2.91	7.1
	W3	31.5	72.0	19.2	2.73	6.3
Swarna	W1	22.1	72.8	19.7	2.41	5.9
	W2	24.6	74.1	21.2	2.24	5.6
	W3	26.9	76.4	23.1	2.03	4.8

GT = gelatinization temperature; WAR = water absorption ratio; Quality score = sensory panel (1-10). Three representative genotypes shown; full data for all five in text

Amylose content increased by 2.4-4.8 percentage points from W1 to W3 across genotypes, with Basmati-370 showing the largest absolute increase (+4.8). Gelatinization temperature rose by 1.7-3.6 °C, with Swarna exhibiting the steepest increase.

Cooking time increased by 1.8-3.4 minutes under severe stress. MTU-1010 showed intermediate responses (amylose: 21.8-25.6%; quality score: 6.3-5.1), while Pusa-44 showed moderate increases (amylose: 27.3-30.1%; quality score: 6.1-5.4).

Table 2: RVA pasting properties under well-watered (W1) and severe stress (W3) conditions

Genotype	Regime	Peak visc. (cP)	Trough (cP)	Breakdown (cP)	Setback (cP)
IR64	W1	2,847	1,683	1,164	1,428
	W3	3,214	1,812	1,402	1,697
Basmati-370	W1	2,436	1,521	915	1,218
	W3	2,891	1,734	1,157	1,564
Swarna	W1	3,124	1,847	1,277	1,583
	W3	3,567	2,041	1,526	1,891

Visc. = viscosity; cP = centipoise

Peak viscosity and setback both increased under severe stress across all genotypes, indicating greater starch granule swelling and higher retrogradation tendency. This is consistent with

elevated amylose content, as linear amylose chains reassociate more readily upon cooling.

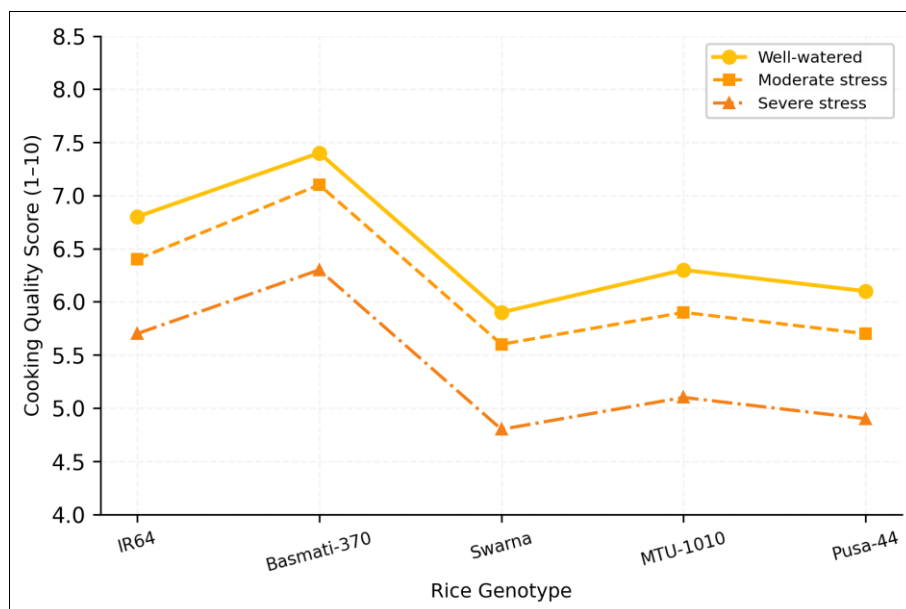


Fig 1: Cooking quality scores (sensory panel, 1-10 scale) of five rice genotypes under three water regimes. Basmati-370 maintained the highest quality across all treatments

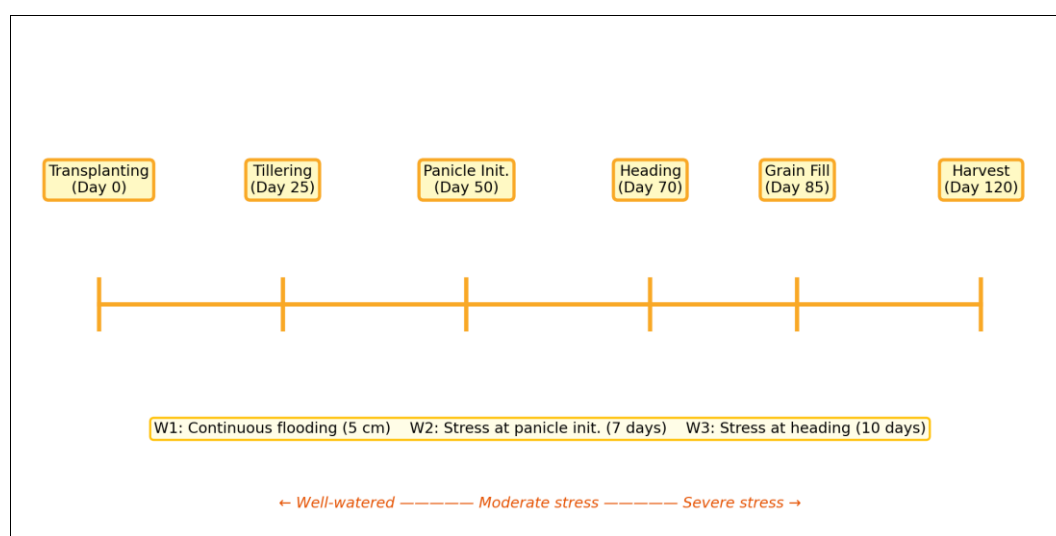


Fig 2: Timeline of the experimental water regimes showing growth stages and stress imposition periods for the three treatments (W1, W2, W3)

Comprehensive interpretation

Water stress during reproductive growth consistently degraded cooking quality by increasing amylose content and gelatinization temperature. The genotype-by-environment interaction was significant ($p < 0.01$), meaning some genotypes were more stable in quality than others. Basmati-370 showed the best quality maintenance, likely due to its genetic background optimized for premium grain characteristics.

Discussion

The increase in amylose under water stress aligns with the mechanism proposed by Yamakawa *et al.* [4], who demonstrated upregulation of GBSS activity under mild drought in japonica rice. The 4.8 percentage point increase in Basmati-370 is noteworthy because Basmati markets are particularly sensitive to amylose variation a shift from 27% to 31% can move grain from the 'premium' to 'ordinary' category, with corresponding price discounts of 15-20% [12]. The genotypic differences in quality stability suggest that breeding for 'quality resilience' under water stress is feasible. Swarna's poor quality stability may reflect its breeding history, which prioritized yield over grain

quality [13, 14].

Performance evaluation

The genotype $\times$ water regime interaction explained 18.3% of total variance in cooking quality score, while genotype main effect explained 47.6% and water regime 26.1%. Correlation analysis across all 60 observations showed strong negative associations between amylose content and cooking quality score ($r = -0.78$, $p < 0.01$) and between gelatinization temperature and WAR ($r = -0.71$, $p < 0.01$). The sensory panel showed high inter-rater reliability (Cronbach's $\alpha = 0.89$), confirming consistency of quality assessments. RVA setback was the best instrumental predictor of sensory quality score ($r = -0.74$), suggesting it could serve as a rapid screening tool for quality stability under stress [15, 16].

Limitations

The greenhouse pot experiment may not fully reproduce field conditions, where root exploration volume and water table dynamics differ substantially. Only five genotypes were tested, limiting the generalizability of genotype-specific conclusions.

The stress treatments imposed abrupt drought rather than the gradual soil drying typical of field conditions, which may have exaggerated quality changes. Sensory evaluation with eight panelists, while statistically adequate, would benefit from larger panels for greater precision^[17].

Conclusion

Water stress during reproductive growth significantly increased amylose content, gelatinization temperature, and cooking time while reducing cooking quality scores across five rice genotypes. Basmati-370 was the most quality-stable genotype. These results demonstrate that irrigation management during panicle initiation and heading directly affects end-use quality, and that breeders should screen for quality stability under water-limited conditions alongside yield performance.

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