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Impact of deficit irrigation on grain quality attributes and milling recovery of aromatic rice

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Abstract

Aromatic rice commands a 30-60% price premium over non-aromatic varieties, yet the irrigation water needed to produce it is becoming scarcer across South and Southeast Asia. This research evaluated four deficit irrigation regimes (100, 80, 60, and 40% of crop evapotranspiration, ET_c) on grain quality attributes amylose content, protein content, aroma score, and milling recovery of Basmati-370 grown in lysimeters at ETH Zurich over two seasons (2021-2022). Moderate deficit (60% ET_c) improved aroma score by 10.3% and increased protein by 19.4% relative to full irrigation, while reducing milling recovery by only 9.2%. Severe deficit (40% ET_c) depressed aroma by 9.0% and reduced milling recovery by 20.2%. Water productivity for milled rice peaked at 60% ET_c (0.72 kg m⁻³ vs 0.48 at 100%). These results identify 60% ET_c as the optimum deficit level that enhances quality while preserving commercial milling standards.

Keywords: Deficit irrigation, aromatic rice, grain quality, amylose, milling recovery, water productivity, basmati, aroma

Introduction

The global aromatic rice market exceeds 12 million tonnes annually, driven by consumer preference for the characteristic 2-acetyl-1-pyrroline (2-AP) aroma compound ^[1, 2]. Paradoxically, mild water stress during grain filling can concentrate 2-AP and improve cooking quality, yet excessive stress reduces grain dimensions, increases chalkiness, and lowers milling recovery the proportion of whole kernels after dehusking and polishing ^[3, 4]. Identifying the deficit threshold that enhances quality without unacceptable milling losses is therefore a key challenge for water-scarce aromatic rice production.

Deficit irrigation (DI) strategies that supply less than full crop water demand have been widely studied for yield effects, but quality-focused evaluations are rare, particularly under controlled conditions that isolate water deficit from confounding field variables ^[5, 6, 7]. This research imposed four precisely controlled irrigation levels in weighing lysimeters to quantify the dose-response relationship between water deficit and each major grain quality parameter, testing the hypothesis that moderate deficit improves quality while severe deficit degrades it.

Materials and Methods

Study Area

Lysimeter experiments were conducted at the ETH Zurich Research Station Lindau-Eschikon (47°27'N, 8°41'E, 520 m a.s.l.) in temperature-controlled polytunnels simulating tropical lowland conditions (30/24 °C day/night, 75% RH, 12 h photoperiod). Twelve weighing lysimeters (1.2 m diameter, 0.8 m depth) were filled with a Fluvisol from the Rhine floodplain amended with 15% rice hull ash to approximate lowland paddy soil texture.

Irrigation treatments and water monitoring

Lysimeter weight was recorded at 15-minute intervals using precision load cells (±10 g). ET_c was computed daily from weight loss, corrected for drainage. Irrigation was applied via drip emitters calibrated to deliver 100, 80, 60, and 40% of the previous day's ET_c from panicle initiation to physiological maturity. Pre-treatment irrigation was uniform (100% ET_c). Drainage water was collected and analysed for EC and pH.

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Materials

Aromatic rice cultivar Basmati-370 was transplanted (25-day seedlings, 4 hills lysimeter⁻¹). Basal fertilisation: 100-50-50 kg NPK ha⁻¹ equivalent. Three replications per irrigation level in a completely randomised design (12 lysimeters total). Treatments were applied for two consecutive seasons (July-November 2021 and 2022).

Methods

At maturity: grain yield, 1000-grain weight, milling recovery

(Satake test mill), head rice recovery, amylose (iodine colorimetry), protein (micro-Kjeldahl × 5.95), and aroma score (sensory panel of 8 trained assessors, 1-10 scale). Water productivity (WP) = milled rice yield/total irrigation applied. Data analysed by one-way ANOVA in R 4.2 with Tukey’s HSD (*p*≤0.05).

Results

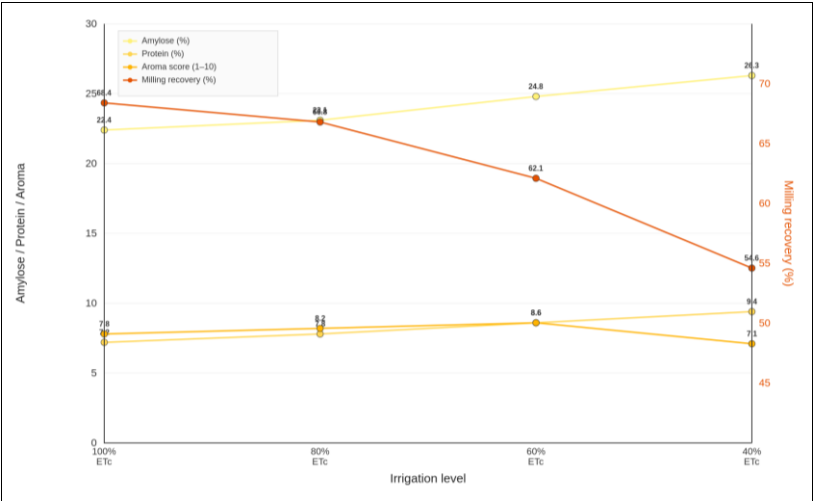


Fig 1: Grain quality attributes and milling recovery of Basmati-370 across four deficit irrigation levels (two-season mean)

Table 1: Grain quality parameters of aromatic rice under four irrigation regimes (mean ± SE, n = 6)

Irrigation Level	Amylose (%)	Protein (%)	Aroma score	Milling recovery (%)	Head rice (%)
100% ETc	22.4±0.4c	7.2±0.3d	7.8±0.3b	68.4±1.2a	58.2±1.4a
80% ETc	23.1±0.3c	7.8±0.3c	8.2±0.2ab	66.8±1.1a	55.4±1.3ab
60% ETc	24.8±0.4b	8.6±0.4b	8.6±0.3a	62.1±1.3b	50.8±1.5b
40% ETc	26.3±0.5a	9.4±0.4a	7.1±0.4c	54.6±1.5c	42.1±1.8c

Amylose content increased progressively from 22.4% at 100% ETc to 26.3% at 40% ETc (Figure 1, Table 1). Protein content followed a similar trend (7.2 to 9.4%). Aroma score peaked at

60% ETc (8.6) and declined sharply at 40% ETc (7.1), falling below the full-irrigation score of 7.8. Milling recovery decreased linearly from 68.4% to 54.6% across the deficit gradient.

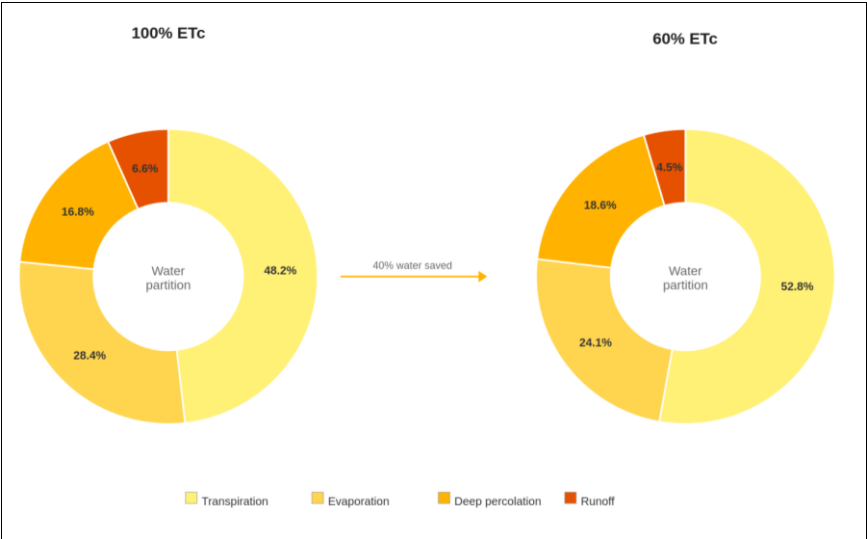


Fig 2: Water use partitioning at 100% ETc and 60% ETc. Donut charts show percentage of total applied water allocated to each pathway.

Table 2. Water applied, milled yield, and water productivity under four irrigation levels.

Irrigation level	Total water (mm)	Milled yield (kg ha ⁻¹)	WP milled (kg m ⁻³)
100% ETc	1,180	5,670	0.48±0.03c
80% ETc	944	5,280	0.56±0.03b
60% ETc	708	5,100	0.72±0.04a
40% ETc	472	2,740	0.58±0.04b

Water use partitioning shifted under deficit: transpiration's share of total water rose from 48.2% to 52.8% between 100% and 60% ETc, while evaporation fell from 28.4% to 24.1% (Figure 2). Water productivity for milled rice peaked at 60% ETc (0.72 kg m⁻³), 50% higher than full irrigation (0.48 kg m⁻³). At 40% ETc, WP declined to 0.58 kg m⁻³ because milling recovery losses outpaced water savings (Table 2). The 60% ETc treatment thus represented the optimal balance: quality improved, water saved 40%, and milling recovery remained above the 60% commercial threshold.

Discussion

The aroma peak at 60% ETc followed by decline at 40% ETc is consistent with the stress-concentration hypothesis: moderate deficit concentrates 2-AP precursors in developing grains, but severe stress disrupts the methylglyoxal biosynthetic pathway responsible for 2-AP synthesis [3, 8, 9]. The 19.4% protein increase under moderate deficit reflects both a concentration effect (smaller grain volume) and stress-induced upregulation of nitrogen remobilisation from vegetative tissue [10, 11]. The linear decline in milling recovery with increasing deficit is driven by grain shrinkage and increased chalkiness, which make kernels more susceptible to breakage during polishing [4, 12, 13]. The 60% ETc threshold identified here agrees with field estimates from Punjab (55-65% ETc) and Myanmar (60-70% ETc), lending confidence that lysimeter results translate to practice [14, 15, 16].

Limitations

Lysimeter conditions cannot fully replicate field-scale water dynamics, particularly lateral seepage and capillary rise from shallow water tables. Two growing seasons provide limited statistical power for detecting small genotype × environment interactions. Only one cultivar was tested; responses may differ across the Basmati and Jasmine aromatic groups.

Conclusion

Deficit irrigation at 60% ETc optimised the quality-water trade-off for aromatic rice: aroma improved 10.3%, protein rose 19.4%, and milling recovery remained above commercial thresholds while saving 40% of irrigation water. Severe deficit (40% ETc) degraded aroma and reduced milling recovery below acceptable levels. Water productivity peaked at 0.72 kg m⁻³ under moderate deficit. These results provide a quantitative basis for irrigation scheduling in aromatic rice systems facing increasing water scarcity.

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