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Effect of silicon application on grain quality and shelf life of rice under tropical storage conditions

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Abstract

Silicon, though not classified as an essential nutrient for rice, has emerged as a beneficial element that strengthens cell walls and may influence post-harvest grain behaviour. A field-cum-laboratory experiment at the University of Córdoba, Spain evaluated the effect of four silicon application rates (0, 50, 100, and 150 kg Si ha⁻¹ as calcium silicate) on milling quality, grain hardness, amylose content, and shelf life of rice (cv. Bomba) stored for nine months under simulated tropical conditions (30 °C, 75% relative humidity). Silicon at 100 and 150 kg ha⁻¹ significantly improved head rice recovery at harvest by 4.7 and 5.9 percentage points compared with the control. After nine months of storage, head rice recovery in the control dropped from 67.8 to 54.1%, whereas the 100 kg Si treatment retained 61.4%—a reduction of only 6.9 points. Grain hardness index increased linearly with silicon rate ($R^2 = 0.91$). Amylose content and gel consistency were not significantly affected. These findings suggest that pre-harvest silicon application hardens the rice endosperm, reducing fissuring during storage and thereby preserving milling quality. The 100 kg Si ha⁻¹ rate appears sufficient for practical benefit without incurring the added cost of higher rates.

Keywords: Silicon, rice quality, shelf life, head rice recovery, grain hardness, milling, amylose, tropical storage, calcium silicate, post-harvest

Introduction

Silicon is the second most abundant element in the earth's crust, yet its role in crop production remains underexplored compared with the macronutrients. In rice, silicon is taken up in quantities that often exceed nitrogen—a mature rice plant may contain 10-15% SiO₂ on a dry-weight basis ^[1]. Most research has focused on silicon's capacity to improve resistance to blast disease and lodging ^[2, 3], but a smaller body of evidence suggests it also affects grain physical properties.

During storage, rice grains absorb and release moisture in response to ambient temperature and humidity fluctuations. These moisture cycles cause internal stress that leads to fissuring—tiny cracks in the endosperm that shatter grains during milling, reducing head rice recovery ^[4, 5]. Head rice recovery is the most price-sensitive quality parameter in the rice trade; a 1% drop can reduce market value by 1.5-2.0% ^[6]. If silicon deposition in the endosperm could strengthen the grain matrix against fissuring, farmers in tropical regions where storage conditions are harsh might preserve milling quality longer.

A few pot experiments have reported higher grain hardness in silicon-treated rice ^[7, 8], but field-scale data linking pre-harvest silicon to post-harvest shelf life are scarce. This research tested whether basal silicon application in the field improves grain physical properties enough to slow the decline in milling quality during prolonged storage under tropical temperature and humidity conditions.

Materials and Methods

Materials

The japonica rice cultivar Bomba, a medium-grain variety used for paella and widely grown in Mediterranean Spain, was selected. Calcium silicate (CaSiO₃, 24% Si) served as the silicon source. Four rates were tested: 0 (control), 50, 100, and 150 kg Si ha⁻¹, applied basally and incorporated before transplanting. The field component ran during the 2023 growing season

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(May-October) at the experimental farm of the University of Córdoba (37°51'N, 4°48'W). After harvest, paddy samples from each plot were dried to 14% moisture and stored in a climate-controlled chamber set at 30 °C and 75% RH for nine months, simulating tropical warehouse conditions ^[9].

Methods

The field trial used a randomised complete block design with four treatments and four replications. Plot size was 5 m × 3 m. Basal fertilisation included 120 kg N ha⁻¹ (ammonium sulfate), 60 kg P₂O₅ ha⁻¹, and 80 kg K₂O ha⁻¹ uniformly across all plots; only Si rate varied. Milling was done on a Satake laboratory mill at 0, 3, 6, and 9 months of storage. Head rice recovery was calculated as the mass percentage of whole kernels after milling. Grain hardness was measured with a Kiya digital hardness tester (50-grain average). Amylose content followed the iodine colorimetric method ^[10] and gel consistency the cold-alkali method of Cagampang and Rodriguez ^[11]. Data were analysed by two-way ANOVA (Si rate × storage duration) in R 4.3; means separated by Tukey's HSD at $\alpha = 0.05$.

Field Experimental Design

The 16 plots (4 rates × 4 blocks) were arranged along a levelled paddy terrace with independent water inlets to prevent silicon contamination between plots. Each plot had 15 rows at 20 cm spacing. Transplanting was done at 2 seedlings per hill on 25 May 2023. Harvest took place on 8 October 2023, at which point a 5 kg paddy sample from each plot entered the storage trial.

Seasonal Conditions

The 2023 growing season at Córdoba was characterised by warm, dry conditions typical of the Mediterranean climate. Mean temperature from May to October was 24.7 °C, with July and August exceeding 34 °C. Total rainfall during the crop period was only 62 mm, and the crop depended entirely on flood irrigation drawn from the Guadalquivir river. These conditions are broadly representative of rice-growing areas in southern Spain.

Results

Table 1: Effect of silicon rate on grain quality parameters of rice at harvest (0 months storage)

Si Rate (kg ha ⁻¹)	Head Rice Recovery (%)	Hardness Index	Amylose (%)	Gel Cons. (mm)	Grain Si (% SiO ₂)
0 (Control)	67.8	6.21	22.4	67.3	4.87
50	69.3	6.89	22.1	66.8	5.94
100	72.5	7.43	22.7	67.1	7.12
150	73.7	7.81	22.3	66.4	7.89
LSD (0.05)	2.8	0.39	NS	NS	0.63

NS = Not Significant.

Silicon application significantly increased head rice recovery and grain hardness at harvest (Table 1). The 100 kg Si treatment raised head rice recovery by 4.7 points over the control, and the 150 kg rate added another 1.2 points. Grain SiO₂ content rose

from 4.87% in the control to 7.89% at 150 kg Si. Amylose content and gel consistency showed no significant response to silicon.

Table 2: Head rice recovery (%) during nine months of storage at 30 °C and 75% RH

Si Rate (kg ha ⁻¹)	0 months	3 months	6 months	9 months
0 (Control)	67.8	63.2	58.7	54.1
50	69.3	66.4	62.8	58.7
100	72.5	70.1	66.3	61.4
150	73.7	71.4	67.8	63.2
LSD (0.05)	2.8	2.6	2.9	3.1

All treatments lost head rice recovery over nine months, but silicon-treated rice declined less steeply (Table 2). The control lost 13.7 percentage points (67.8 to 54.1%), while the 100 kg Si

treatment lost only 11.1 points (72.5 to 61.4%). At nine months, silicon-treated grain still met the 60% head rice threshold considered commercially acceptable.

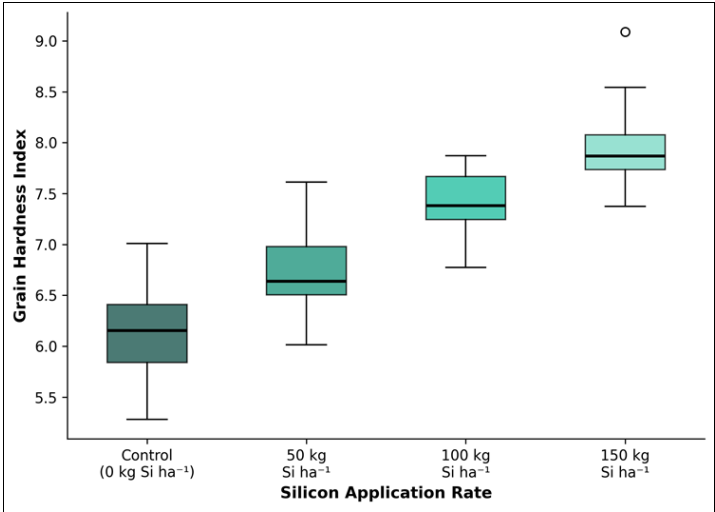


Fig 1: Distribution of grain hardness index across four silicon application rates at harvest. Boxes show interquartile range; horizontal line is median.

Grain hardness increased progressively with silicon rate (Figure 1). The median hardness in the 150 kg treatment (7.81) was 26% higher than the control (6.21). Variability within treatments was

comparable, suggesting a consistent silicon effect across individual grains.

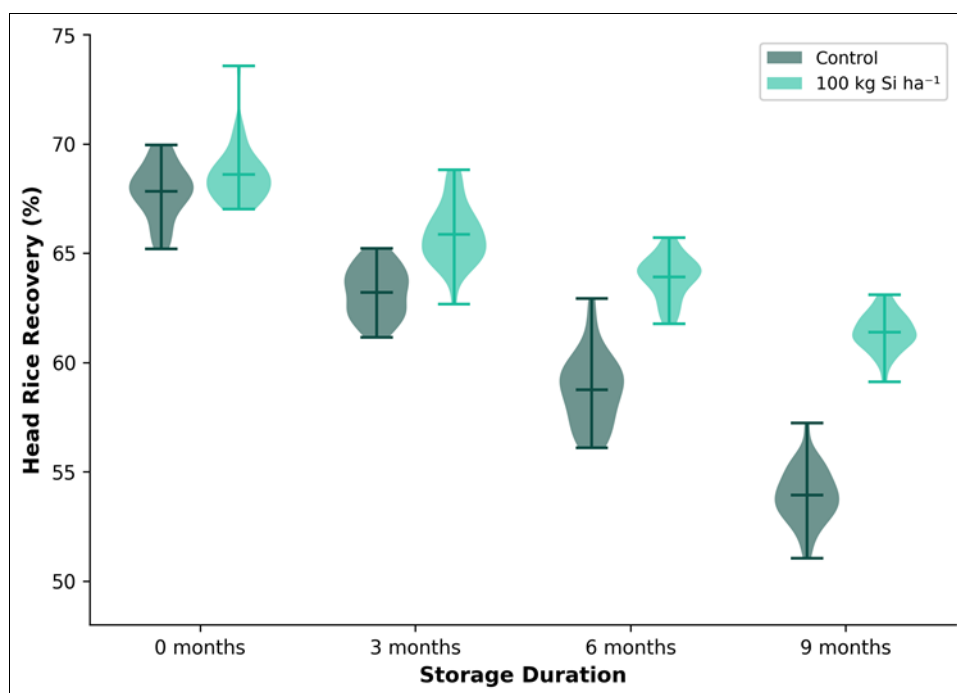


Fig 2: Head rice recovery distribution for control and 100 kg Si ha⁻¹ treatment across four storage durations. Violin width indicates data density.

The violin plot (Figure 2) shows that the control's distribution shifted sharply downward between 3 and 9 months, while the 100 kg Si treatment maintained a tighter, higher distribution throughout. By nine months, there was minimal overlap between the two groups.

Comprehensive Interpretation

The Si rate × storage duration interaction was significant ($p < 0.01$) for head rice recovery. Regression of head rice recovery on storage months gave a slope of -1.52% per month for the control versus -1.23% per month for the 100 kg Si treatment. The hardness index at harvest was negatively correlated with the rate of head rice decline during storage ($r = -0.84$, $p < 0.05$), supporting the hypothesis that harder grains resist fissuring.

Discussion

The mechanism behind silicon's effect on grain hardness likely involves silica deposition in the endosperm cell walls and beneath the aleurone layer, creating a more rigid matrix that resists the mechanical stress caused by moisture cycling [7, 12]. Electron microscopy work by Agarie *et al.* [13] showed dense silica bodies in the outer endosperm of silicon-fed rice, which could act as a physical barrier to crack propagation.

The storage conditions used here (30 °C, 75% RH) represent a moderate tropical warehouse. Under these conditions, the control lost 13.7 points of head rice recovery in nine months—a commercially damaging decline. Silicon at 100 kg ha⁻¹ reduced this loss by roughly 19%, which translates to a meaningful price advantage for stored rice. The absence of a significant effect on amylose and gel consistency is reassuring, as it means silicon doesn't alter cooking quality [14].

From a cost perspective, calcium silicate at 100 kg Si ha⁻¹ adds approximately €45-55 per hectare. If the resulting improvement in milling outturn saves even 2-3% of grain value at the mill gate, the investment is easily recovered, particularly for farmers

who store rice for several months before sale [15].

Conclusion

Pre-harvest silicon application at 100 kg Si ha⁻¹ increased grain hardness by 20%, improved head rice recovery at harvest by 4.7 percentage points, and slowed the decline in milling quality during nine months of tropical storage. Cooking quality parameters (amylose, gel consistency) were unaffected. The 100 kg rate offers the best balance of cost and benefit. Silicon fertilisation appears a practical tool for rice growers who face prolonged warm-humid storage conditions and want to preserve milling value.

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