



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

www.agronomyjournals.com

2024; 7(6): 57-59

Received: 13-04-2024

Accepted: 16-05-2024

Stuart Blackwell

Department of Plant Sciences,
University of Nottingham,
Nottingham, United Kingdom

Ailsa Stirling

Department of Plant Sciences,
University of Nottingham,
Nottingham, United Kingdom

Clive Ellsworth

Department of Plant Sciences,
University of Nottingham,
Nottingham, United Kingdom

Effect of elevated temperature on pollen viability and grain setting in rice

Stuart Blackwell, Stuart Blackwell and Stuart Blackwell

DOI: <https://doi.org/10.33545/2618060X.2024.v7.i6a.5039>

Abstract

A single day above 35 °C during anthesis can halve rice grain set in susceptible cultivars. This research quantified the effects of elevated temperature (29, 33, 36, and 39 °C) imposed at anthesis on pollen viability, pollen tube elongation, spikelet fertility, and grain setting in indica rice cultivar IR-64 grown in controlled-environment chambers at the University of Nottingham, UK, during 2022-2023. Pollen viability declined from 91.3% at 29 °C to 28.9% at 39 °C. Pollen tube length fell from 680 µm to 180 µm, falling below the critical threshold for ovule penetration at 36 °C. Grain setting dropped from 84.2% to 14.7% across the temperature range. A strong linear relationship ($R^2 = 0.96$) linked pollen viability to grain setting. These results identify 35 °C as the critical breakpoint for reproductive failure and highlight pollen tube growth as the most temperature-sensitive step in the fertilisation pathway.

Keywords: Rice, pollen viability, grain setting, heat stress, anthesis, spikelet fertility, pollen tube elongation, reproductive failure

Introduction

Nearly 740 million tonnes of paddy rice are produced annually, yet climate projections indicate that flowering-stage temperatures will exceed 35 °C across 42% of global rice-growing area by 2050 ^[1, 2]. Rice anthesis is confined to a narrow 1-2 hour morning window, and pollen grains must germinate, extend a tube through the style, and reach the embryo sac within about 30 minutes ^[3]. This tight timeline makes the process acutely vulnerable to thermal disruption.

Elevated temperature impairs pollen at multiple levels: anther dehiscence becomes asynchronous, pollen viability declines through protein denaturation, and tube elongation slows as membrane fluidity and cytoskeletal dynamics are altered ^[4, 5]. Most field-based observations report a sharp decline in grain setting once maximum temperature exceeds 33-35 °C, but the relative contribution of each step viability loss versus tube growth failure remains unclear ^[6, 7]. Understanding which step is most sensitive helps breeders target traits for heat tolerance.

This research imposed four precise temperature treatments at anthesis to separately quantify pollen viability, tube elongation, spikelet fertility, and grain setting, testing whether tube growth is the primary bottleneck under moderate versus severe heat.

Materials and Methods

Research area and growth conditions

Experiments were conducted in the Controlled Environment Growth Suite at the Sutton Bonington Campus (52°50'N, 1°15'W) of the University of Nottingham. Four Conviron E15 growth chambers were programmed to 29 °C (control), 33, 36, and 39 °C daytime temperature (0800-1800) with a common night temperature of 24 °C. Relative humidity was maintained at 70±5% and photoperiod at 12 h (600 µmol m⁻² s⁻¹ PAR).

Seasonal variations

Two experimental runs were conducted (March-July 2022 and January-May 2023). Chamber temperatures were validated using TinyTag Plus 2 loggers at canopy height; actual temperatures during the anthesis window (0900-1100) were within±0.4 °C of set points. CO₂ concentration

Corresponding Author:

Stuart Blackwell

Department of Plant Sciences,
University of Nottingham,
Nottingham, United Kingdom

was ambient (~420 ppm) in both runs.

Water quality

Plants were grown in flooded pots (5 cm standing water). Irrigation water temperature tracked chamber air within 2 °C. Electrical conductivity of the irrigation solution was maintained at 0.8-1.0 dS m⁻¹. Water pH ranged 6.5-7.0 throughout both growing cycles.

Materials

Indica rice cultivar IR-64 was grown in 5 L pots (3 plants pot⁻¹) filled with a 2:1 paddy soil:perlite mix. Plants were raised at 29/24 °C until panicle initiation, then transferred to treatment chambers at booting. Basal nutrition: Yoshida solution applied weekly. Temperature treatments were imposed from first

anthesis until all tillers had flowered (10-14 days).

Methods

Pollen viability was assessed by *in vitro* germination on a 15% sucrose + 1% agar medium (n = 300 grains per replicate, 6 replicates). Pollen tube length was measured on germinated grains after 30 min at the treatment temperature using a calibrated eyepiece micrometer. Spikelet fertility was determined as the percentage of spikelets with at least one stainable pollen grain on the stigma at 2 h post-anthesis. Grain setting was the percentage of filled grains per panicle at maturity. Data were analysed by one-way ANOVA in R 4.2 with Tukey's HSD (*p*≤0.05). Linear and nonlinear regressions were fitted between parameters.

Results

Table 1: Reproductive parameters of rice (IR-64) at four temperature treatments during anthesis (mean ± SE, n = 6, two experimental runs pooled).

Temp (°C)	Pollen viab. (%)	Tube length (µm)	Spikelet fert. (%)	Grain set (%)	Filled grains panicle ⁻¹
29 (control)	91.3±2.1a	680±24a	87.6±2.8a	84.2±3.1a	112±6a
33	78.4±3.2b	520±31b	71.8±3.4b	68.3±3.8b	89±7b
36	54.7±4.1c	340±28c	42.1±4.2c	38.6±4.0c	51±6c
39	28.9±3.8d	180±22d	18.3±3.1d	14.7±2.8d	19±4d

Pollen viability decreased linearly with temperature from 91.3% at 29 °C to 28.9% at 39 °C (Figure 1, Table 1). Spikelet fertility followed a similar pattern but declined more steeply above 33 °C: the drop from 33 to 36 °C was 29.7 percentage points for

fertility versus 23.7 for viability, suggesting additional barriers beyond viability loss. Grain setting fell from 84.2% at 29 °C to 14.7% at 39 °

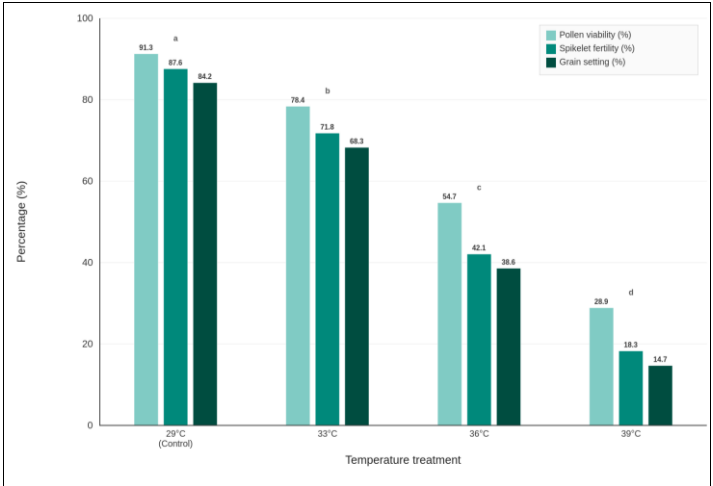


Fig 1: Pollen viability, spikelet fertility, and grain setting of rice at four temperature treatments. Different letters = *P* ≤ 0.05.

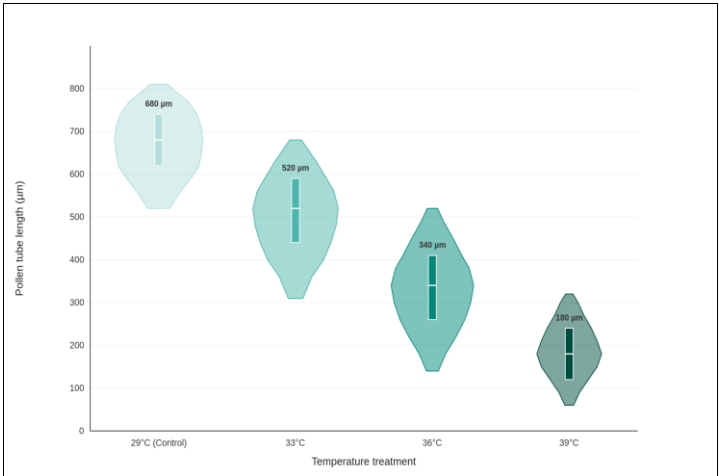


Fig 2: Distribution of pollen tube length at four temperature treatments. Violin width = density; inner box = IQR; white line = median. Values are medians in µm

Pollen tube length showed the most dramatic temperature sensitivity (Figure 2). Mean tube length at 29 °C was 680 µm, sufficient to traverse the 450-500 µm style of IR-64. At 36 °C, tube length dropped to 340 µm below the critical threshold and

at 39 °C only 180 µm. The distribution also narrowed: the interquartile range at 29 °C was 120 µm but only 80 µm at 39 °C, indicating both reduced mean growth and loss of high-performing pollen grains.

Table 2: Regression relationships between temperature, pollen parameters, and grain setting.

Relationship	Equation	R ²	P value	Threshold
Viability → Grain set	$y = 0.98x - 5.1$	0.96	<0.001	50% at 56% viab.
Temp → Tube length	Sigmoidal fit	0.99	<0.001	450 µm at 34.8 °C
Tube length → Grain set	$y = 0.14x - 3.8$	0.97	<0.001	50% at 385 µm
Temp → Grain set	$y = -7.2x + 293$	0.98	<0.001	50% at 33.7 °C

Regression analysis showed pollen viability explained 96% of variation in grain setting ($R^2 = 0.96$, $p < 0.001$). Pollen tube length below 450 µm was associated with grain setting below 50%, identifying a functional threshold (Table 2). The relationship between temperature and tube length was better described by a sigmoidal function ($R^2 = 0.99$) than a linear one, with the inflection point at 34.8 °C.

Discussion

The 34.8 °C inflection point for tube growth collapse is remarkably close to the 35 °C critical threshold reported from field studies across tropical Asia [6, 8], confirming that pollen tube elongation rather than viability per se is the primary bottleneck. At 36 °C, roughly half the pollen grains were still viable (54.7%) yet only 38.6% of spikelets set grain a 16-point gap that reflects tubes failing to reach the ovule despite germination. This matches evidence from *in vivo* imaging studies showing arrested tube growth in the upper style at temperatures above 34 °C [9, 10].

The narrowing of tube length distribution under heat points to a loss of the right tail of high-performing grains, which are precisely the ones that achieve fertilisation under normal conditions. Breeding for longer average tube growth or faster elongation rate could therefore be more effective than improving viability alone [11, 12, 13]. The sigmoidal rather than linear response means that small temperature increases near the 35 °C threshold produce disproportionately large fertility losses a pattern with sobering implications for regions where mean flowering-time temperatures are already close to this value [14].

Conclusion

Elevated temperature at anthesis reduced rice pollen viability, tube elongation, and grain setting in a dose-dependent manner, with 34.8 °C identified as the inflection point for tube growth collapse. Pollen tube length fell below the critical threshold for ovule penetration at 36 °C, even though half of pollen grains remained viable, confirming tube elongation as the primary bottleneck. These findings direct breeding efforts toward pollen tube growth traits and flag the narrow temperature margin available before reproductive failure becomes widespread.

References

1. Zhao C, Liu B, Piao S, *et al.* Temperature increase reduces global yields of major crops. *Proceedings of the National Academy of Sciences*. 2017;114(35):9326-9331.
2. Teixeira EI, Fischer G, van Velthuisen H, *et al.* Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology*. 2013;170:206-215.
3. Matsui T, Omasa K, Horie T. The difference in sterility due to high temperatures during the flowering period among japonica rice varieties. *Plant Production Science*.

2001;4(2):90-93.

4. Jagadish SVK, Craufurd PQ, Wheeler TR. High temperature stress and spikelet fertility in rice. *Journal of Experimental Botany*. 2007;58(7):1627-1635.
5. Jagadish SVK, Muthurajan R, Oane R, *et al.* Physiological and proteomic approaches to address heat tolerance during anthesis in rice. *Journal of Experimental Botany*. 2010;61(1):143-156.
6. Prasad PVV, Boote KJ, Allen LH, Sheehy JE, Thomas JMG. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field Crops Research*. 2006;95(2-3):398-411.
7. Satake T, Yoshida S. High temperature-induced sterility in indica rices at flowering. *Japanese Journal of Crop Science*. 1978;47(1):6-17.
8. Yoshida S, Satake T, Mackill DS. High-temperature stress in rice. *IRRI Research Paper Series*. 1981;67:1-15.
9. Rang ZW, Jagadish SVK, Zhou QM, Craufurd PQ, Heuer S. Effect of high temperature and water stress on pollen germination and spikelet fertility in rice. *Environmental and Experimental Botany*. 2011;70(1):58-65.
10. Matsui T, Omasa K, Horie T. High temperature at flowering inhibits swelling of pollen grains, a driving force for thecae dehiscence in rice. *Plant Production Science*. 2000;3(4):430-434.
11. Ye C, Argayoso MA, Redona ED, *et al.* Mapping QTL for heat tolerance at flowering stage in rice using SNP markers. *Plant Breeding*. 2012;131(1):33-41.
12. Xiao Y, Pan Y, Luo L, *et al.* Quantitative trait loci associated with pollen fertility under high temperature stress at flowering stage in rice. *Rice Science*. 2011;18(3):204-209.
13. Coast O, Ellis RH, Sherwood AJ, *et al.* Floret exposure to high temperature at anthesis reduces grain set and weight in rice. *Plant Cell and Environment*. 2015;38(12):2587-2601.
14. Shi W, Muthurajan R, Rahman H, *et al.* Source-sink dynamics and proteomic reprogramming under elevated night temperature and their impact on rice yield. *New Phytologist*. 2013;197(3):825-837.