

Economic Effects of Extreme Heat on Rice Yield and Milling Quality in Arkansas

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Introduction

Current climate change models project mean global temperature increases between 1.8 °C and 4 °C by 2100,¹ threatening roughly one billion people who depend on rice cultivation as their primary income source, and the food security of roughly 3.5 billion people.² Past analyses of extreme heat effects on rice production have focused on paddy yield,^{3,4} and have not accounted for the detrimental impact of extreme heat on milling quality outcomes which ultimately determine edible (marketable) rice yield. Therefore, existing estimates^{3,4} of the implications of future increases in mean growing season temperature likely understate true economic and food security implications.

Objectives

- I. To model impact of extreme heat on
 1. Paddy (rough) rice yield (kg·ha⁻¹); and,
 2. Milling quality elements:
 - a. Milled rice yield (MRY, %);
 - b. Head rice yield (HRY, %); and,
 - c. Chalk content (CHALK, %).
- II. To estimate changes producer and miller revenue per hectare given results from (I).
- III. To accomplish (I) and (II) in such a way that accounts for unique genotypic responses to extreme heat.

Methods

Paddy Yield

OLS fixed-effects multiple regression is used to estimate paddy yield:

$$(1) Y_{isj}^p = \mathbf{a}W_{isj} + \mathbf{b}_s + \mathbf{c}_j + \varepsilon_{isj},$$

where, Y_{isj}^p is the natural logarithm of yield; W_{isj} is a vector of growth window specific explanatory variables including mean daily temperature and solar radiation, extreme heat exposure variables (defined below); \mathbf{b}_s is a vector of station intercepts; \mathbf{c}_j is a vector of varietal intercepts; and ε_{isj} is the error term.

Milling Quality

Generalized method of moments (GMM) is used to estimate the following milling quality system for each variety:

$$(2) Y_{is}^C = \alpha^C X_{is} + \mathbf{b}_s + u_{is}^C,$$

$$(3) Y_{is}^H = \alpha^H X_{is} + \gamma^H Y_{is}^C + \beta_{21}^H HMC_{is} + \beta_{22}^H HMC_{is}^2 + \mathbf{b}_s + u_{is}^H, \text{ and}$$

$$(4) Y_{is}^M = \alpha^M X_{is} + \beta_{31}^M HMC_{is} + \mathbf{b}_s + u_{is}^M,$$

where, X_{is} is a vector of extreme heat exposure variables corresponding to the grain filling stages at which extreme heat affects milling quality outcomes; HMC_{is} is harvest moisture content (%) which affects milling quality independently of temperature; and \mathbf{b}_s is a vector of station intercepts.

We define total (day and night) extreme heat exposure (TDN) during growth window k ($W_k \forall k = 1, 2, 3$) as:

$$TDN_{W_k} = \left[\sum_{D \in W_k} \sum_{t \in D} T(t) - 33 \right] + \left[\sum_{N \in W_k} \sum_{t \in N} T(t) - 22 \right]$$

$$D = \{t \mid T(t) > 33, \text{ sunrise} < t < \text{ sunset} \}$$

$$N = \{t \mid T(t) > 22, \text{ sunrise} > t > \text{ sunrise} \}$$

This measure approximates the sum of the red and orange areas shown in Figure 1.

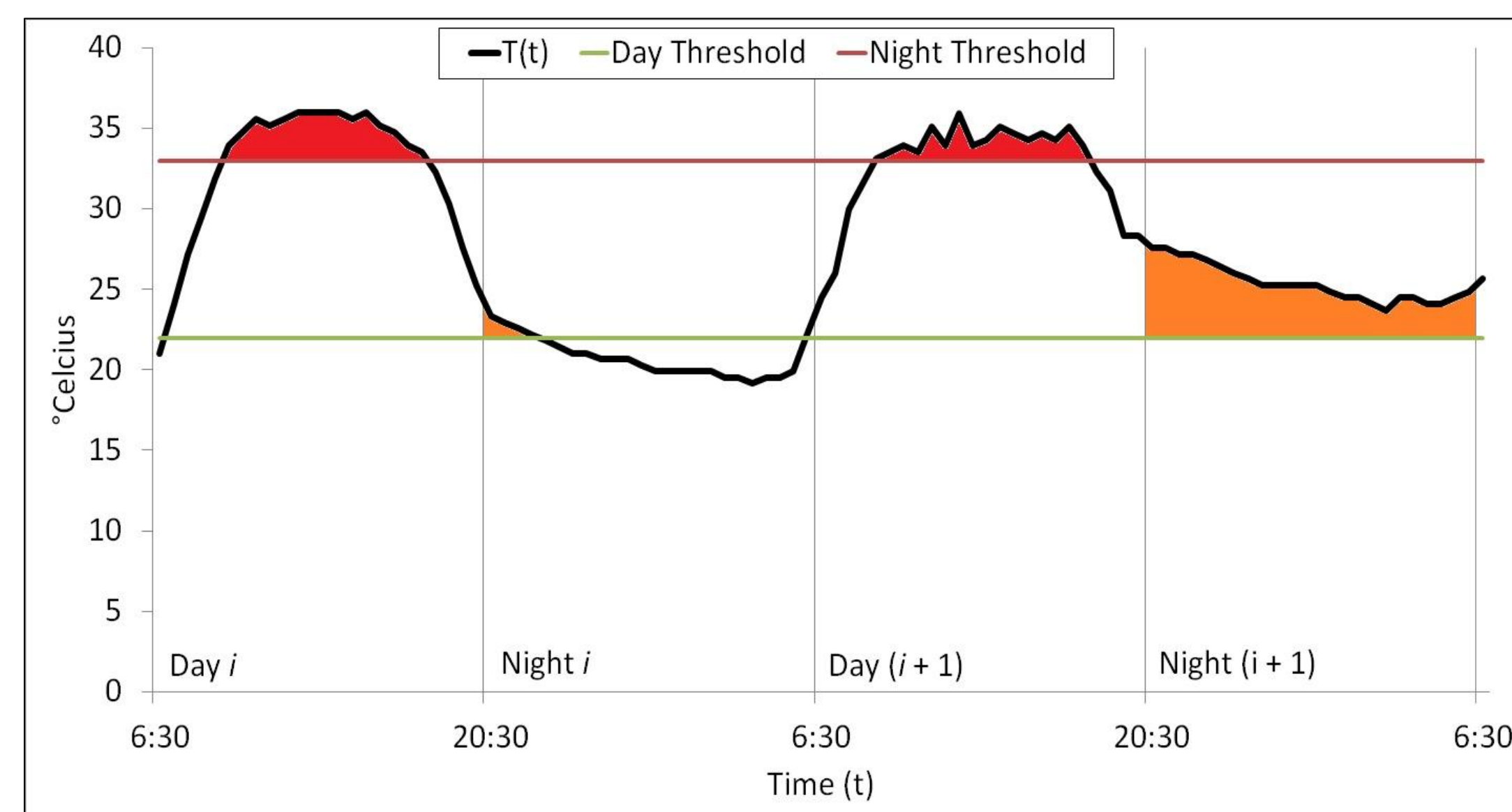


Figure 1: Extreme heat accumulation variable description.

Results & Discussion

Paddy Yield

Estimated effects of extreme heat on paddy yield are negative and statistically significant at the vegetative and early reproductive stages.

Figure 2 | Extreme temperature effects on paddy rice yield.

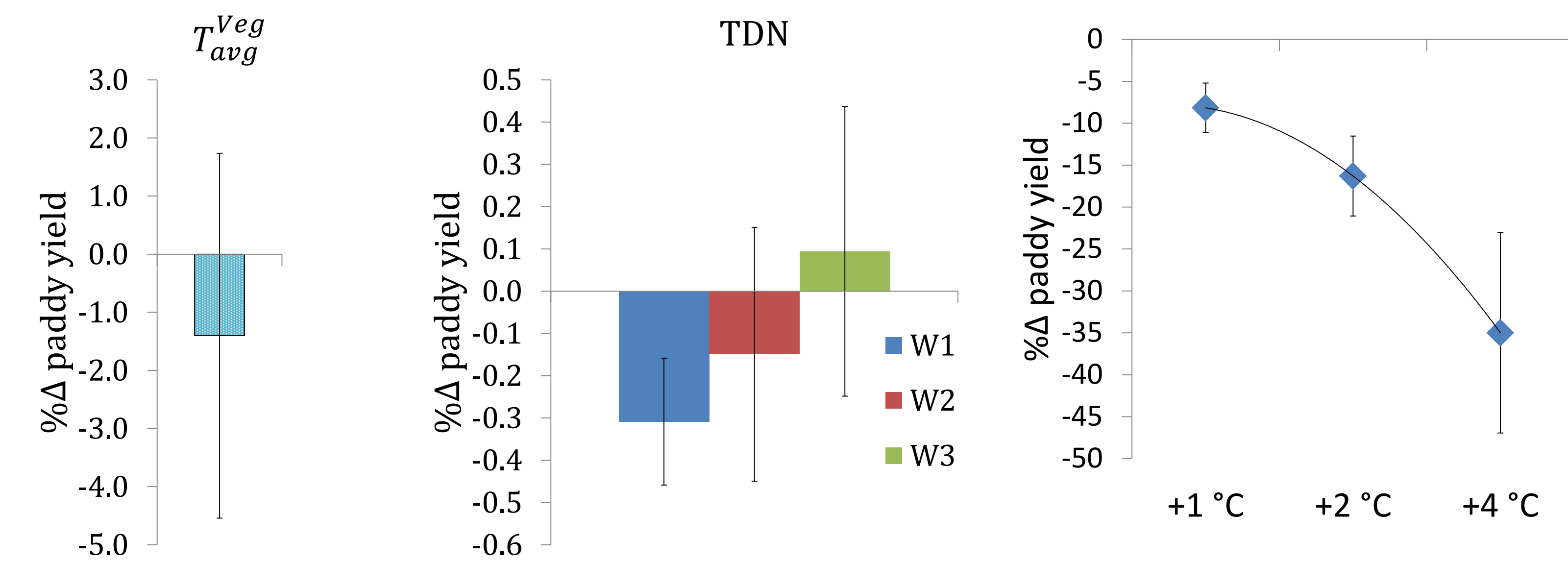


Figure 2 illustrates the nonlinear effect of extreme heat on paddy yield. These results are consistent with past analyses of paddy yield^{3,4} and provide a baseline for determination of milling quality effects on mass milled rice per unit area depicted below. Extreme heat has a clear, negative effect on the quantity of edible, milled rice and distribution of quality given increased temperatures. The approach followed in this study provides a template for future analyses of the economic impacts of climate change on rice production.

Milling Quality

Figure 3 | Nonlinear response of mean milled rice outcomes given 1, 2, and 4 °C increases in mean growing season temperature, by genotype

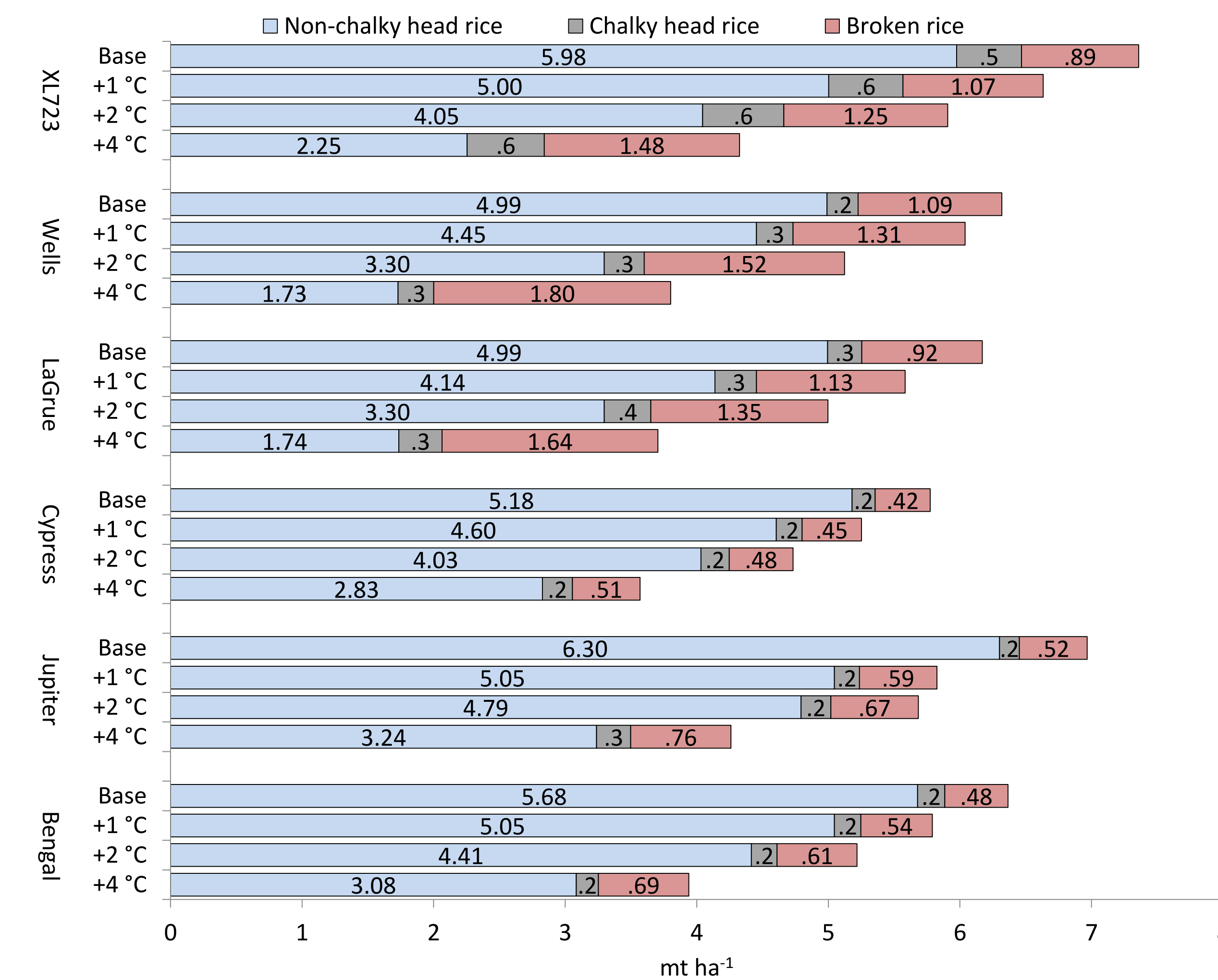
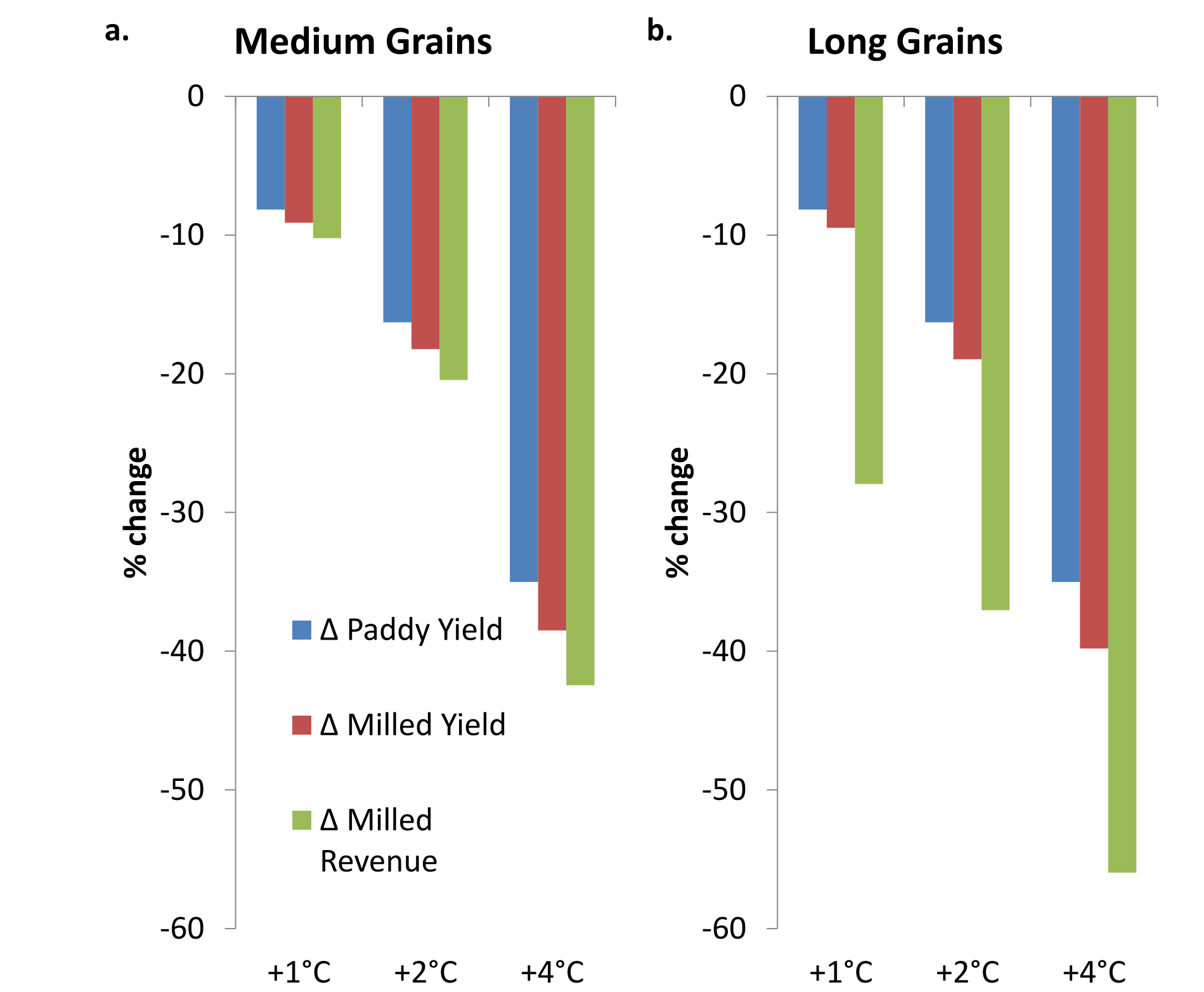


Figure 4 | Mean percentage changes in paddy yield, milled yield and milling revenue by grain length



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