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Published by NSW Department of Primary Industries,
a part of the Department of Regional New South Wales.

Light interception and radiation-use efficiency in wheat varieties with contrasting heat stress tolerance

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Key findings

- Wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass.
- Radiation-use efficiency was more closely related to grain yield in the heat-tolerant varieties than in the sensitive varieties.
- The results suggest that breeding for heat tolerance would deliver benefits for wheat growers, even under optimal growing conditions.

Introduction

Heat stress is estimated to cost Australian wheat growers $1.1 billion annually in yield losses (Thomas 2015). During daylight hours, the rising temperature in the field can result in heat stress, especially in dry conditions when cooling by evaporation is no longer able to keep pace with incident radiation (incoming radiation from the sun). The leaf canopy temperatures at midday can often be higher than that of the surrounding air. This can cause irreversible damage to the photosynthetic apparatus (the chloroplast), resulting in:

- rapid loss of chlorophyll (Shirdelmoghanloo et al. 2016a)
- reduced grain filling period (Shirdelmoghanloo et al. 2016b)
- shrivelled grains that significantly reduce grain yield and marketable quality.

Heat stress tolerance has been shown to vary in some Australian wheat varieties (Collins et al. 2017; Sissons et al. 2018). However, the physiological mechanism underlying the variability in tolerance is not fully understood. From a grower perspective, this knowledge is relevant for targeting tolerant varieties to two aspects of heat stress:

1. the gradual increase in temperature that reduces grain yield potential through reduction of photothermal quotient
2. the extreme, heat-shock events that disrupt reproductive process and reduce grain number (Sadras & Dreccer 2015).

It has often been noted that at midday, plants can change their architecture by folding the leaves or by changing the leaf orientation from horizontal to vertical. There is anecdotal evidence to suggest that they can avoid heat stress damage in this way. However, regulating the amount of incident radiation absorbed by the canopy could affect grain yield, since biomass production is dependent on the crop canopy's ability to intercept radiation.

In this experiment, we sought to determine whether wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass. Delayed sowing was used to expose the crop to rising temperatures.

Site details

Site	Wagga Wagga Agricultural Institute
Sowing dates	5 June (early sowing) and 1 August (late sowing) 2015
Disease management	Fungicide: Bumper® 625EC 200 mL/ha, @ 250 L water rate.

Weed control	Knockdown: Spray.Seed® 2 L/ha, Roundup 1.25 L/ha, 100 L/ha water rate Pre-emergent: Boxer Gold® 2.5 L/ha, TreflanTM 480 2 L ha, 100 L/ha water rate In-crop: first post-emergent: Terbutrex® 600 g/ ha, Lonestar® 13 g/ha, 100 L/ha water rate Second post-emergent: Affinity® 100 mL/ha, Agritone® 750 330 mL/ha, 100 L/ha water rate
Treatments	Wheat varieties of contrasting tolerance to heat stress
Sowing dates	Early (June) and late (August)
Experiment design	Spatially optimised incomplete block design

Glossary of terms

PAR = Photosynthetically active radiation. This is the part of the solar radiation spectrum that is used for photosynthesis (in the 400 to 700 nanometer wavelength range).

fPAR = Fraction of PAR received at the crop canopy surface.

IPAR = Amount of PAR intercepted by the crop.

RUE = Radiation-use efficiency. The above-ground dry matter produced per unit of intercepted PAR.

PTQ = Photothermal quotient. Ratio of intercepted PAR and mean temperature.

PTQvpd = Photothermal quotient (PTQ) adjusted for moisture stress.

Method

Wheat varieties were selected on the basis of greenhouse and chamber screening for variation in heat tolerance. Field experiments were conducted under irrigation, using two planting dates in 2015. Ceptometer readings were taken once a week for each plot using the AccuPAR LP-80 (Decagon Devices Inc.). Measurements were confined to midday (10 am to 2 pm) during the period of Zadok growth stage 33–65. At each measurement time, three readings were taken per plot, one above the canopy (PAR_{above}), and two below the canopy (PAR_{below}). From these measurements, the fraction of photosynthetically active radiation received by the crop (fPAR) was calculated as the ratio of the difference between PAR_{above} and PAR_{below} to PAR_{above}, and the intercepted radiation (IPAR) was determined as the product of fPAR and total solar radiation (MJ m^{-2}) derived from the Scientific Information for Land Owners (SILO) climate database (https://silo.longpaddock.qld.gov.au). A photothermal quotient (PTQ) was calculated for each variety as the ratio between intercepted PAR and mean daily temperature above a base temperature of 4.5 °C. The PTQ was also adjusted for vapour pressure deficit (PTQvpd) calculated according to Dreccer et al. (2007).

To determine above-ground biomass, a quadrat sample of each variety was taken at maturity. Radiation-use efficiency (RUE) was calculated as the ratio of plant biomass at maturity and cumulative IPAR during the period of ~20 days before and 10 days after anthesis.

Results and discussion

The varieties used for this experiment showed high harvest indices, most likely due to using full irrigation to ensure no drought stress. Late sowing exposed the crops to rising temperatures, which had a significant effect on varietal trait expression. The IPAR, biomass production and RUE were all significantly higher in the early sown treatment compared with the late-sown treatment. Sowing date also significantly affected grain yield being higher in the early-sown (4.98 t /ha) than the late-sown (3.01 t/ha) treatment. However, grain size (1000 grain weight) was not affected (37.9 g vs 37.4 g) and the harvest index was higher in the late-sown than in the early-sown treatment (0.66 vs 0.58, respectively).

The photothermal quotient adjusted for vapour pressure deficit (PTQvpd), which summarises the weather conditions (temperature and moisture) for different sowing dates into a single value, ranged from 3.8 to 5.2 in the early sowing, and from 1.3 to 2.2 in the late sowing. It was linearly related to grain yield, and highly responsive to sowing dates (Figure 1A).

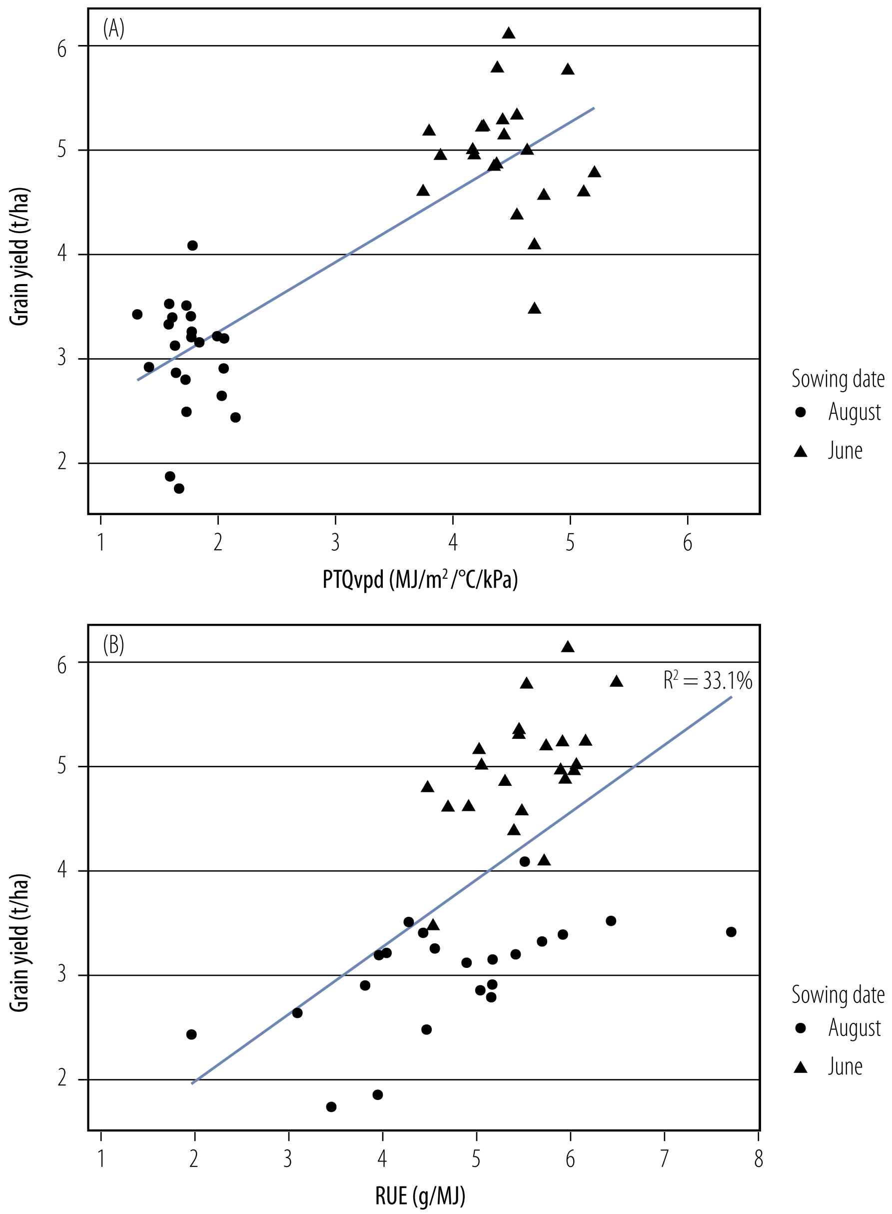

Figure 1. Relationships of grain yield with (A) PTQvpd, and with (B) RUE in experiments conducted at Wagga Wagga in 2015.

Across varieties and sowing dates, RUE explained ~33% of the variability in grain yield (Figure 1B). The relationship was consistent across sowing dates, but not when varieties were classified as heat tolerant (HT) versus sensitive (HS). In the early-sown treatment, 56% of the grain yield produced by heat tolerant varieties was explained by RUE, compared with 6.4% in the sensitive varieties (Figure 2A). Under heat stress conditions induced by late-sowing, the contribution of RUE to grain yield was ~50% in the heat-tolerant varieties, and 20% in the sensitive varieties (Figure 2B).

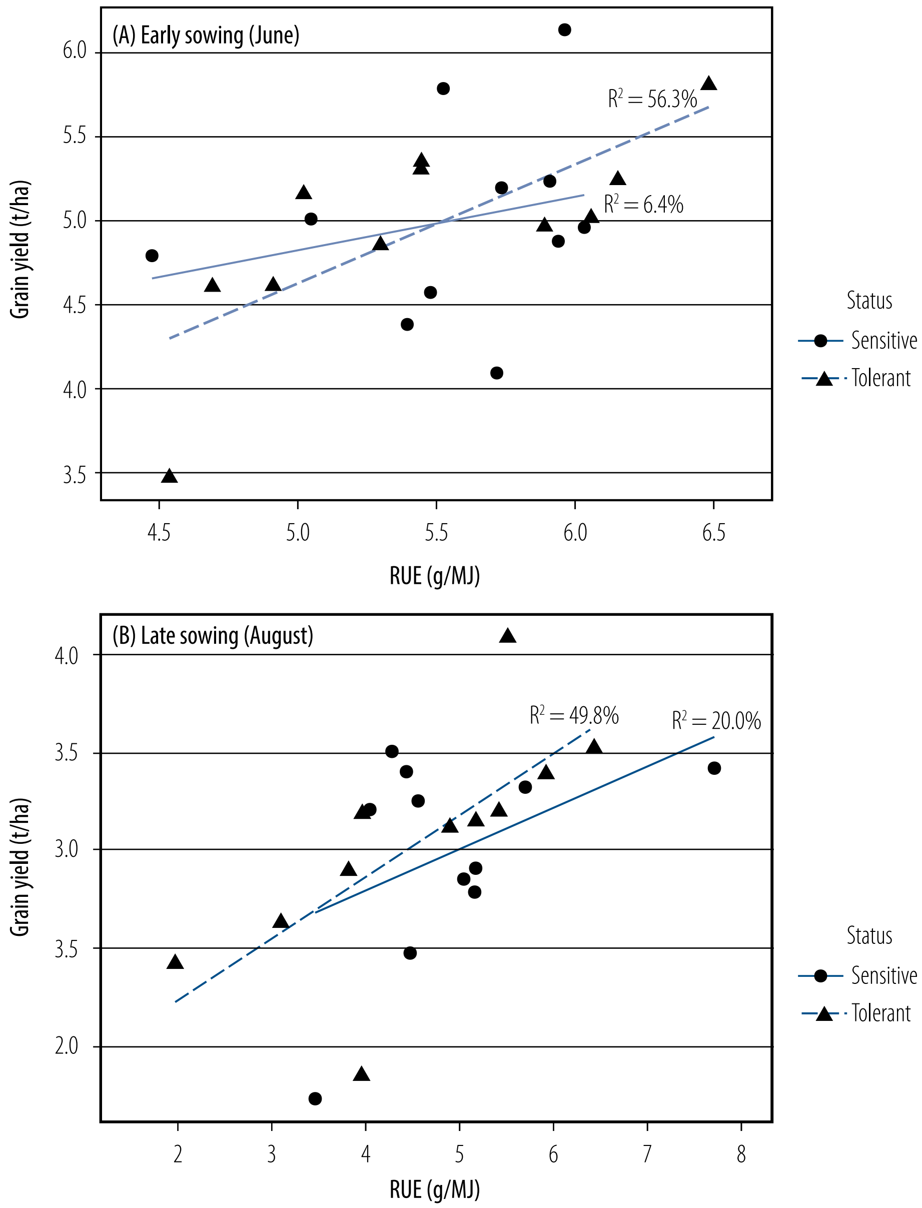

Figure 2. Relationships of grain yield (t/ha) with RUE in wheat varieties differing in heat tolerance, for the early (A) and late (B) sowing dates.

Summary

Although this is a preliminary experiment, the results suggest that wheat varieties that differ in heat tolerance also differ in their ability to capture incident light energy and to convert the energy into biomass. The heat tolerant varieties were better able to use intercepted photosynthetically active radiation for grain yield production compared with the sensitive group. The large difference observed under normal sowing (56% vs 6.4%) suggests that breeding for heat tolerance would deliver benefits for wheat growers even under optimal growing conditions. The experiments will be repeated to confirm results.

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Acknowledgements

This experiment was part of the project 'Genetic analysis of heat tolerance in wheat', UA00147, 2014–18, with joint investment by GRDC, NSW DPI and University of Adelaide.

Technical assistance from Danial Newton and Warren Burdach is gratefully acknowledged.