Effects of zinc on photosynthesis and yield of wheat under heat stress

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ABSTRACT

Maintaining grain yield and quality in climates characterised by periods of high temperature stress is an ongoing problem for the wheat industry, but the role of zinc (Zn) nutrition in providing plants with tolerance to heat stress has been largely overlooked. We examined the interaction between Zn nutrition and heat stress on the photosynthetic activity and grain yield of wheat plants under both field and growth room conditions. The Zn inefficient cultivar Goldmark was found to have an improved chlorophyll fluorescence ratio (Fv/Fm), a measure of injury to photosynthesis, under heat stress when supplied with elevated levels of Zn compared to plants where less Zn was applied. However supplementary Zn did not prevent a decline in kernel weight or grain yield under high temperature conditions. The results indicate that supplementary Zn nutrition, in a Zn inefficient genotype at least, can provide thermotolerance to the photosynthetic apparatus of wheat.

KEY WORDS

Wheat, zinc, high temperature, chlorophyll fluorescence.

INTRODUCTION

High temperature stress is a major cause of yield loss in cereal crops throughout many of the world’s cereal growing areas, including Australia. Furthermore, much of the Australian wheat belt most exposed to high temperatures also has soils deficient in zinc (Zn). Elevated temperatures cause deleterious changes in a number of physiological processes, including disruption of membranes (2), while Zn deficiency also reduces membrane integrity (12). This suggests a possible link between zinc deficiency and susceptibility to heat stress, and, further, that Zn efficient genotypes may show a greater degree of thermotolerance than Zn inefficient genotypes. Zn efficiency is defined as the ratio of plant growth under deficient and adequate Zn supply (5), and is an indicator of genotypic tolerance to low supplies of Zn. Very few studies to date have examined the relationship between Zn nutrition and thermotolerance in plants, and these investigations have been confined primarily to the response of seedlings to Zn ions and heat shock *in vitro* (3, 7). The main aim of this study was to determine if elevated supplies of Zn could maintain photosynthetic activity and grain yield in wheat plants exposed to heat stress.

MATERIALS AND METHODS

Pot experiment

Plants were grown in a Zn-deficient siliceous sandy soil (Laffer sand) with $CaCO_3$ and basal nutrients added (4). Zinc treatments were 0.2 and 2 mg Zn kg^{-1} soil applied as $ZnSO_4.7H_20$ (designated as $Zn_{0.2}$ and Zn_2). Ten pre-germinated seeds of 4 bread wheat genotypes (*Triticum aestivum* L. cvv. Frame, Goldmark, Halberd and Meering) were sown into 2 L pots containing 3 kg of soil. The experiment was set up in a completely randomised block design with 4 replicates. Plants were grown in a growth chamber at 22/16?C day/night with a 14 h photoperiod. Heat treatments (40/20?C, 14 h photoperiod) were applied for 3 d starting from 10 days after anthesis (DAA). The rate of heating to, and cooling from 40?C was 7?C h^{-1}. Adequate soil moisture was maintained during this period. The chlorophyll fluorescence ratio (Fv/Fm) was measured on flag leaves using a Hansatech Plant Efficiency Analyser (Hansatech Instruments Ltd., King’s Lynn, UK). Leaf chlorophyll concentration was measured using a SPAD 501 meter (Minolta Instruments, Inc., Osaka, Japan). At maturity 2 plants from each pot were harvested and grain number and grain dry weight was recorded.

Field experiment

Six bread wheats (cvv. Excalibur, Frame, Goldmark, Halberd, Meering and Trident) and one durum wheat (*Triticum durum* cv. Kronos) were sown in 3 row plots on two sowing dates, 25 July (SD 1) and 11 September (SD 2) 1998, at the Waite Institute, South Australia. A foliar spray of $ZnSO_4.7H_2O$ (570 g Zn ha^{-1}) was applied at anthesis and control plots had no Zn applied. The experiment was set up as a split plot design, with 3 replicates. Sowing dates were the main plots and the two Zn treatments were the subplots. Fertiliser (80 kg N ha^{-1}, 34 kg P ha^{-1} and 95 kg K ha^{-1}) was applied at stem elongation and urea (19 kg N ha^{-1}) was applied at anthesis. Plots were frequently irrigated to avoid drought stress. Flag leaf chlorophyll fluorescence was measured in three genotypes, Frame, Meering and Goldmark. At maturity 10 main stem ears were harvested per plot and grain number and grain dry weight was recorded.

RESULTS

Photosynthetic activity and chlorophyll concentration

In the pot experiment, 3 d of high temperature reduced Fv/Fm in all genotypes during the heat stress period and the ensuing 24-48 h (Fig.1). The reduction in Fv/Fm by high temperature was significantly greater in Meering (a thermosensitive variety (9)) and significantly lower in Halberd (thermotolerant (13)). In Goldmark (zinc-inefficient), Zn_2 plants gave a significantly higher Fv/Fm reading during the first two days of high temperature than $Zn_{0.2}$ plants. This phenomenon was also seen in Halberd on the third day of heat stress. In the field both Goldmark and Meering with no supplemental Zn showed a decrease in Fv/Fm when the ambient temperature was 35?C early in grain filling (Table 1).

High temperature reduced the chlorophyll concentration of Meering and Goldmark following the heat stress treatment (Fig. 1). The interaction of Zn fertilisation and high temperature on chlorophyll concentration was not significant, although the $Zn_{0.2}$ plants of Goldmark showed a consistently lower chlorophyll concentration following heat stress than the Zn_2 plants.

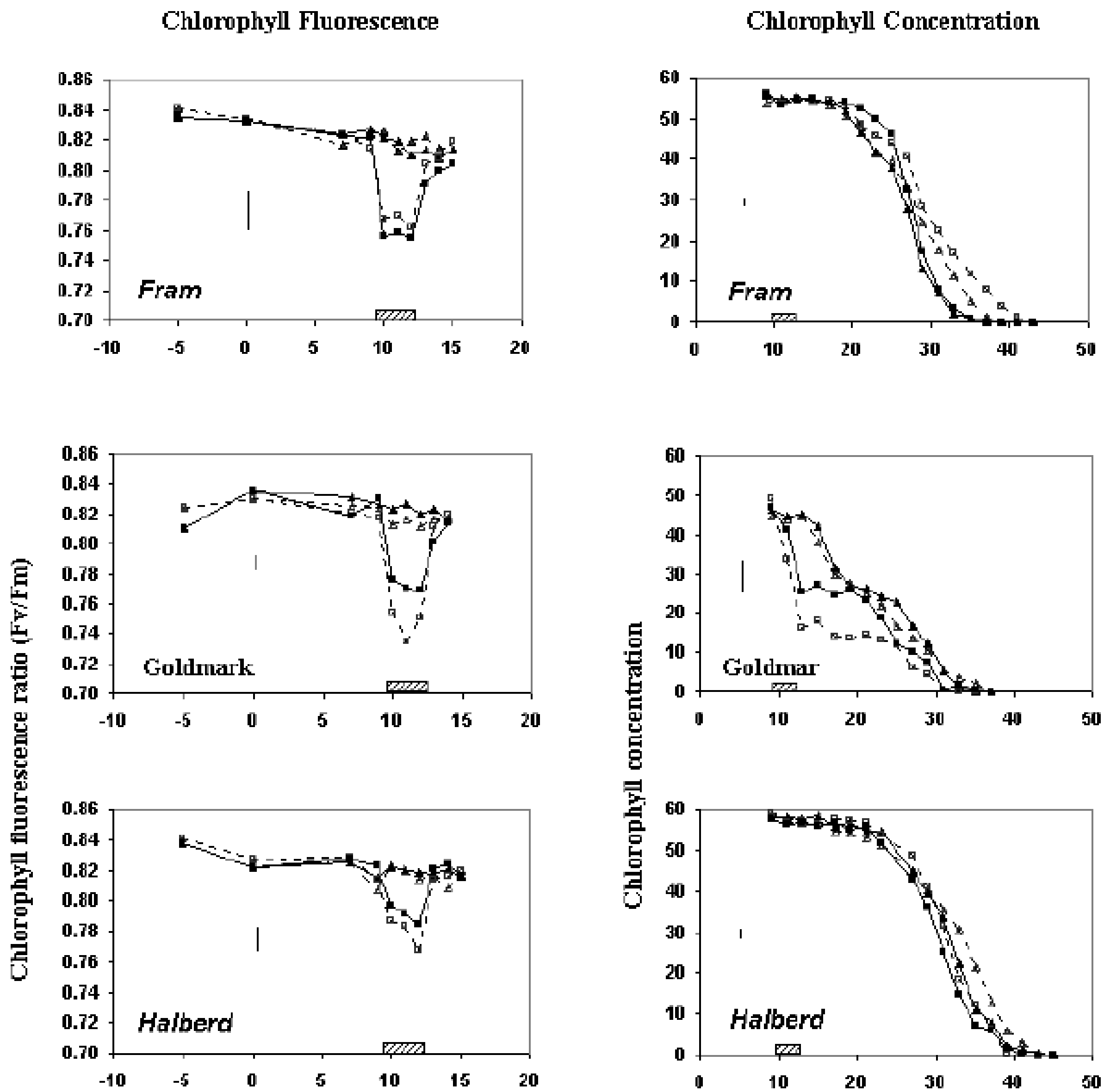
Kernel weight and grain yield

In the pot experiment high temperature stress significantly reduced kernel weight and grain yield in both Goldmark and Meering (Table 2). Elevated zinc fertilisation increased the grain weight of both Frame and Halberd, but this did not increase yield. Zinc fertilisation increased grain number in Goldmark, resulting in increased yield. Zinc fertilisation did not affect the response to high temperature. In the field, neither sowing date nor Zn fertilisation had any effect on grain yield, grain number or kernel weight, with the exception of Excalibur, which had a significantly lower kernel weight at SD 2.

DISCUSSION

Chlorophyll fluorescence yield is a sensitive indicator of changes in thylakoid membrane integrity caused by environmental stresses (8). These results, from both field and controlled environment experiments, demonstrate that the decline in Fv/Fm caused by high temperature can be reduced by elevated Zn fertilisation, at least in a Zn inefficient wheat genotype. This effect was observed in Meering in the field experiment only, but this may be due to the increased severity of the heat stress under the controlled environment conditions (constant 40?C for 6 h compared with 35?C for 3-4 h in the field). Although elevated Zn reduced the decline of Fv/Fm of Goldmark during heat stress, this did not result in an increased kernel weight of the Zn_2 plants. However deprivation of assimilate does not generally account for the high temperature reduction of kernel weight in wheat (10), instead it is the reduction in activity of the soluble starch synthase enzyme that limits grain filling under high temperature, as the conversion of sucrose to starch is impaired (6).

Some researchers (1) have demonstrated a strong correlation between the photosynthetic activity and grain yield of plants exposed to heat stress during grain filling. However it may be that the sensitivity of the photosynthetic apparatus to high temperature reflects the response of other metabolic processes to heat stress, or that carbohydrate supply only indirectly influences grain weight through effects on other organs, such as the roots (11). The response of yield to high temperature in our experiments was more closely related to changes in flag leaf chlorophyll concentration than loss of thylakoid activity. High temperature reduced chlorophyll content in both Meering and Goldmark, but not in Frame or Halberd, and this was reflected in the kernel weight and grain yield of these genotypes.



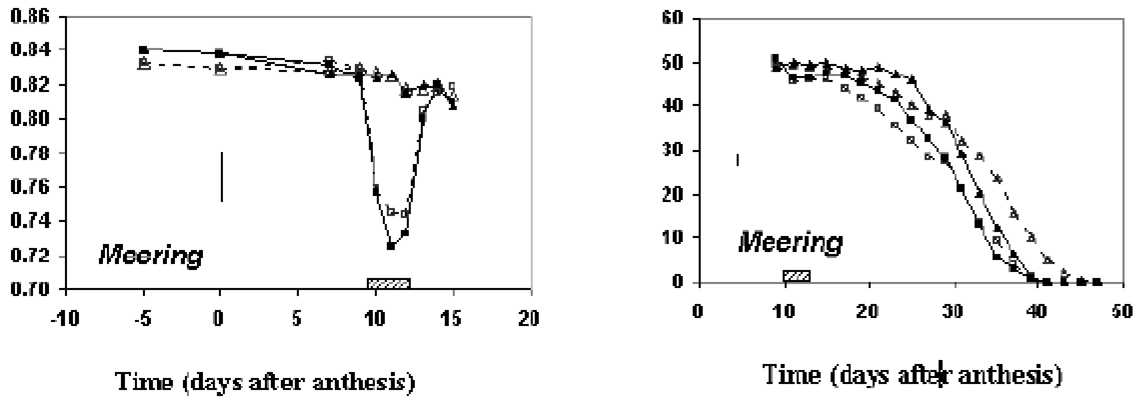


Figure 1. Effect of high temperature treatment and Zn fertilisation on the chlorophyll fluorescence ratio and chlorophyll concentration of four wheat genotypes differing in Zn efficiency and thermotolerance. Control; △$Zn_{0.2}$ and ▲Zn_2: Heat treatment; □$Zn_{0.2}$ and ■Zn_2. Vertical bars are LSDs (*P*=0.05) for the interaction of Zn fertilisation x high temperature treatment at 11 DAA. Hatched horizontal bars represent the period of high temperature treatment.

Table 1. Effect of a Zn spray on the flag leaf chlorophyll fluorescence ratio (Fv/Fm) of three field grown wheat genotypes on 2 consecutive days during grain filling in 1998. Means ? S.E., n=3.

Time after anthesis (d)	Temperature (?C)	Genotype	Fv/Fm	
			-Zn	+Zn
5	35	Goldmark	0.673 ? 0.031	0.754 ? 0.021
		Frame	0.779 ? 0.007	0.769 ? 0.002
		Meering	0.764 ? 0.016	0.798 ? 0.002
6	20	Goldmark	0.756 ? 0.032	0.790 ? 0.014
		Frame	0.797 ? 0.005	0.763 ? 0.023
		Meering	0.821 ? 0.005	0.795 ? 0.020

Table 2. Effects of genotype, high temperature treatment and Zn fertilisation (mg kg^{-1} soil) on the grain weight (mg) (and grain yield (mg $plant^{-1}$)) of wheat under controlled environment conditions.

	Genotype			
	Frame	Goldmark	Halberd	Meering

				Genotype x temperature				
Temperature								
Control	24.98	(1039)	24.94	(1041)	29.43	(1111)	23.29	(1010)
High	25.96	(1035)	21.36	(798)	29.80	(1105)	20.14	(867)
LSD (*P*=0.05)	n.s.	n.s.	2.62	(137)	n.s.	n.s.	2.62	(137)
				Genotype x Zn fertilisation				
Zn fertilisation								
0.2	24.18	(1056)	23.81	(841)	27.76	(1051)	21.36	(885)
2	26.75	(1018)	22.49	(998)	31.47	(1164)	22.07	(992)
LSD (*P*=0.05)	2.62	n.s.	n.s.	(137)	2.62	n.s.	n.s.	n.s.

CONCLUSIONS

We have shown that supplementary Zn fertilisation can improve the photosynthetic activity of a Zn inefficient wheat genotype under heat stress conditions. However, supplementary Zn did not prevent the decline in kernel weight or grain yield of thermosensitive genotypes under high temperature. These results, which must be considered preliminary in nature, indicate that elevated Zn nutrition has the potential to provide thermotolerance to the photosynthetic apparatus of wheat. Further work will be necessary to confirm this relationship, and to establish whether circumstances exist in which this Zn-induced thermotolerance may result in an increase in grain yield.

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REFERENCES

1. Al-Khatib, K. and Paulsen, G.M. 1990. *Crop Sci.* 30, 1127-1132.

2. Berry, J. and Bj?rkman, O. 1980. *Ann. Rev. Plant Physiol.* 31, 491-543.

3. Bonham-Smith, P.C., Kapoor, M. and Bewley, J.D. 1987. *Plant Physiol.* 85, 575-580.

4. Dong, B., Rengel, Z. and Graham, R.D. 1995. *Plant and Soil.* 173, 275-285.

5. Graham, R.D. 1984. *Adv. Plant Nutr.* 1, 57-102.

6. Jenner, C.F. 1994. *Aust. J. Plant Physiol*. 21, 791-806.

7. Repka, V. 1993. *Biol. Plant.* 35, 617-627.

8. Schreiber, U. and Berry, J.A. 1977. *Planta*. 136, 233-238.

9. Stone, P.J. and Nicolas, M.E. 1995. *Aust. J. Agric. Res.* 46, 475-492.

10. Wardlaw, I.F., Sofield, I. and Cartwright, P.M. 1980. *Aust. J. Plant Physiol.* 7, 387-400.

11. Wardlaw, I.F. and Wrigley, C.W. 1994. *Aust. J. Plant Physiol.* 21, 695-703.

12. Welch, R.M., Webb, M.J. and Loneragan, J.F. 1982. *Proceedings of the 9th International Plant Nutrition Colloquium.* Warwick University, England. pp. 710-715.

13. Wrigley, C.W., Blumenthal, C., Gras, P.W. and Barlow, E.W.R. 1994. *Aust. J. Plant Physiol.* 21, 875-885.