Response to boron toxicity in boron efficient and inefficient wheat genotypes

Supannika Punchana, Sansanee Jamjod and Benjavan Rerkasem

Agronomy Department, Faculty of Agriculture, Chiang Mai University, Chiang Mai, 50200 Thailand, Email g4668006@cm.edu

Abstract

Significant wheat yield reductions have been attributed to boron (B) deficiency and toxicity all over the world. However, it is as yet unclear how the two responses are related in wheat genotypes. The relationship between responses to B toxicity and deficiency in wheat genotypes was examined in two experiments. In the first experiment, three genotypes with known B deficiency responses, Fang 60 (Efficient; E) Bonza and Turkey 1473 (Inefficient; I), were grown for 23 days in sand culture with five levels of B added to nutrient solution (10, 50, 100, 150, 200 mg B L^{-1}). Effects of B toxicity were measured in root and shoot length, tiller number, and toxicity symptoms (leaf necrosis and chlorosis). The toxic effect of B on root length and leaf chlorosis and necrosis clearly indicated that Bonza was the most tolerant and Fang 60 least tolerant to B toxicity. In the second experiment the 18th Semi-arid Wheat Screening Nursery from CIMMYT (18th SAWSN, 180 entries) was evaluated for tolerance to B deficiency with grain set in a sand culture without added B and for tolerance to B toxicity with root length at 100 mg B L^{-1}. Three types of response to B deficiency and toxicity by individual genotypes were identified, (i) B efficient, but sensitive to toxicity; (ii) B inefficient, but tolerant to toxicity; (iii) B inefficient and sensitive to toxicity. The fourth type, B efficient, as well as tolerant to toxicity, the ideal, was not found in this international germplasm collection.

Media summary

Wheat varieties that are tolerant to boron deficiency may be prone to B toxicity, and those that are tolerant to B toxicity may be susceptible to B deficiency. However, tolerance to B deficiency and toxicity of wheat varieties are not exactly mirror images of one another. Many varieties that are sensitive to B deficiency can also be sensitive to B toxicity.

Key Words

Boron toxicity, wheat genotypes, boron deficiency tolerance

Introduction

Boron (B) toxicity can occur in arid and semi-arid area such as in India (Takkar 1982), South Australia (Cartwright et al. 1984) and Turkey (Kalayci et al. 1998). Wheat cultivation in B toxic area results in B toxicity symptoms such as chlorosis, necrosis and yield reduction. There is a wide range of genotypic variation in response to B deficiency (Rerkasem and Jamjod 1997) and toxicity (Paull et al. 1991). Wheat breeding programmes in Turkey and Australia seek to improve tolerance to B toxicity, while those on low B soils should aim to improve B efficiency (Rerkasem et al. 2004). One of the most B-efficient genotypes is Fang 60, identified in Thailand (Jamjod et al. 1992), is now being incorporated as a genetic source for B efficiency in the international wheat-breeding programme at CIMMYT. Since B-deficient and B-toxic soils have been found to occur in close proximity (from Australia to Turkey), B fertilizer may also be applied unevenly. The mechanism for tolerance to B toxicity of wheat varieties is generally believed to be associated to the ability to maintain lower B in the shoot (Nable et al. 1988). While it remains unclear how some wheat genotypes are able to yield better than others in low B soils (Rerkasem and Jamjod 1997), it will be useful to know how tolerance and efficiency traits of individual genotypes are related.

Methods

In experiment 1, three wheat genotypes with known B efficiency, Fang 60 (Efficient; E), Bonza and Turkey 1473 (Inefficient; I), were grown in sand culture in 0.3 m. diameter earthenware pots containing washed river quartz sand with ten seeds of each genotype. The pots were watered twice daily with complete nutrient solution at five levels of added B (10, 50, 100, 150 and 200 mg B L^{-1}), referred to B10, B50, B100, B150 and B200, respectively. The complete nutrient solution consisted of $CoSO_4$ (0.1 ?M) Na_2MoO_2 (0.1 ?M) $CuSO_4$ (0.2 ?M) $ZnSO_4$ (0.5 ?M) $MnSO_4$ (2 ?M) FeEDTA (10 ?M) K_2SO_4 (250 ?M) $MgSO_4$ (250 ?M) KH_2PO_4 (500 ?M) $CaCl_2$ (1,000 ?M) and KNO_3 (5,000 ?M) (Broughton and Dilworth 1971). Genotypes and B treatments were arranged in a completely randomized design with two factors and three replications. At 23 days after sowing, root length (the longest seminal root) and shoot length (the coleoptile length) (cm.), tiller number (presented as relative tiller number; (tiller no. at B+/tiller no. at B10) x 100), necrosis (%) and chlorosis (%) symptoms in YEB (the Youngest Expanded Blade) and YEB+1 (the second Youngest Expanded Blade) (Paull et al. 1990) were measured. Percentage of necrosis was evaluated from (necrosis length/length of that leaf) x 100 and chlorosis from (chlorosis length/length of that leaf) x 100. Data were analyzed by analysis of variance (AOV). Significant differences between means were calculated by the LSD test at 95% probabilities.

In experiment 2, 137 entries of wheat from the 18th SAWSN were evaluated for tolerance to B deficiency with grain set without added B, and for tolerance to B toxicity with root length at 100 mg B L^{-1}. The B deficiency evaluation was conducted in a similar sand culture as in experiment 1, at two levels of added B, 0 and 10 µM. Plants were grown to maturity, and the response to low B was assessed as the grain set index (GSI; measured as percentage of the 20 basal florets from 10 spikelets with grain, Rerkasem and Loneragan 1994), with Fang 60 and Bonza SW 41 as B efficient and inefficient controls, respectively. The response to B toxicity was evaluated in a drip tray method (adapted from Campbell et al. 1998; with nutrient solution formula of Webb and Loneragan (1990) and Haynes and Robbins (1948)) with two levels of B, 0 and 100 mg B L^{-1}, with Bonza as the control genotype. The relative B response was measured as the length of the longest seminal root in B100 as % of the length in B0.

Results

Experiment 1

Boron toxicity depressed root length, shoot length and caused necrosis and chlorosis on wheat leaves. Differential responses to B toxicity among the three wheat genotypes with different tolerance to B deficiency were obvious in root length (Figure 1a) and leaf symptoms (Figures 2, 3) but not in shoot length (Figure 1b). The B efficient Fang 60 was clearly the most sensitive to B toxicity, and Bonza the most tolerant.

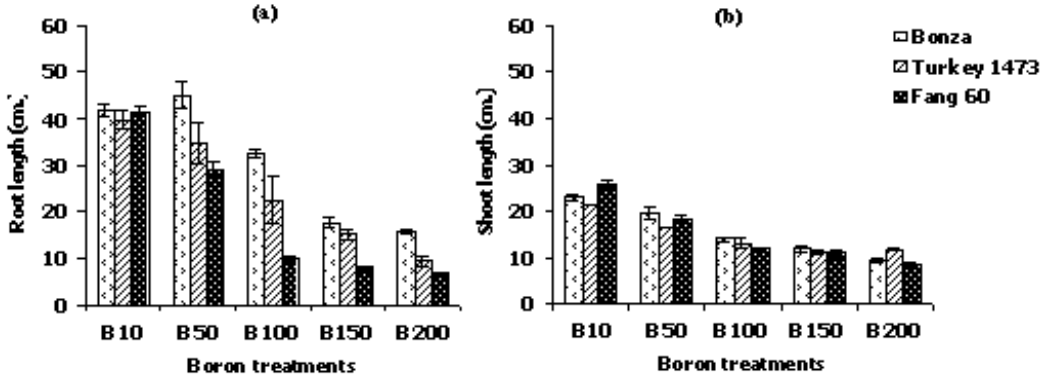

Figure 1. (a) Root length (cm.) and (b) shoot length (cm.) of three wheat genotypes grown in sand culture with five B treatments at 23 days after sowing. Vertical bars presented as standard error of 3 replications. (1a) BxG (significant at p < 0.01), (1b) BxG* (significant at p < 0.05). B = boron, G = genotype.**

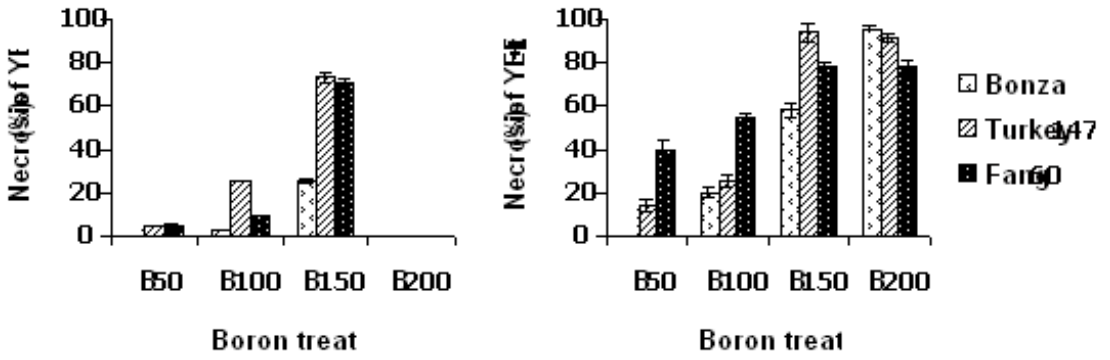

Figure 2. Effect of B treatments on necrosis (%) of YEB and YEB+1 of three wheat genotypes grown in sand culture at 23 days after sowing. Vertical bars presented as standard error of 3 replications. BxG^{ns} (YEB), BxG* (YEB+1) (^{ns} non significant at p < 0.05, * significant at p < 0.05). B = boron, G = genotype.

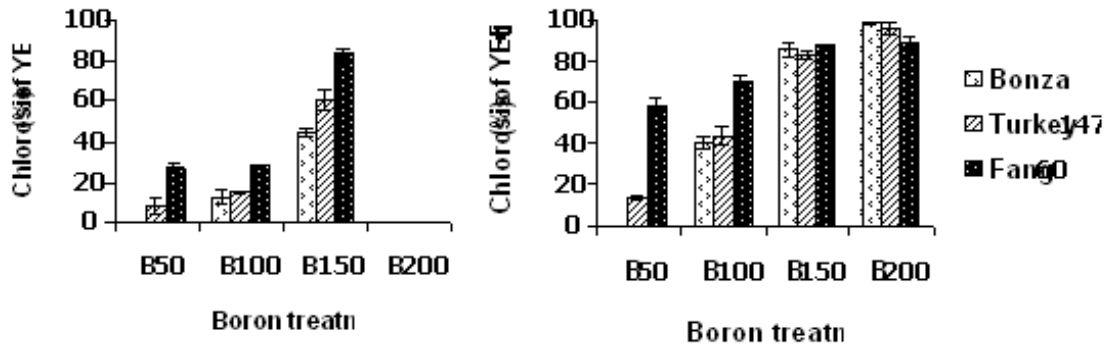

Figure 3. Effect of B treatments on chlorosis (%) of YEB and YEB+1 of three wheat genotypes grown in sand culture at 23 days after sowing. Vertical bars presented as standard error of 3 replications. BxG^{ns} (YEB), BxG* (YEB+1) (^{ns} non significant at p < 0.05, * significant at p < 0.05). B = boron, G = genotype.

Experiment 2

In a sand culture without added B in which GSI of the check genotypes were 91.8?1.4% for Fang 60, 3.8?4.1 for Bonza, entries in the 18th SAWSN ranged in GSI from 0% to 92.9?0.8%. However, average GSI for the whole nursery was only 33.0?25.5%, and three quarters of the nursery was considered B inefficient, with GSI <50% (Table 1). Those entries with a GSI in the low B condition >80% are in the same B efficiency class as Fang 60, but accounted for only 5% of the nursery. The predominance of low grain set in low B conditions, indicative of B inefficiency, in the 18th SAWSN is typical of the international germplasm from CIMMYT (Rerkasem et al. 2004). Relative root length in B100 compared with Bonza, on the other hand, indicates tolerance to B toxicity. Those entries with the relative root length significantly lower than Bonza, considered sensitive to B toxicity, accounted for more than half of the nursery. By examining the distribution of toxicity tolerance in each B efficiency class, the relationship between efficiency and tolerance responses of individual genotypes may be established. All of the B-efficient genotypes were found to be sensitive to B toxicity, just like Fang 60. Boron-tolerant genotypes, however, accounted for only half of the B-inefficient entries. The other half are either sensitive to very sensitive to B toxicity. The mechanism for B tolerance in wheat varieties is generally believed to be associated with the ability to maintain lower B in the shoot (Nable et al. 1988). Uptake efficiency may be a key mechanism that operates in both responses to deficiency and toxicity. However, the mechanism for B efficiency is likely to be much more complex.

Table 1. Frequency distribution of wheat genotypes in different classes of tolerance to B deficiency (by GSI in B0) and toxicity (by relative root length in B100 compared with toxicity tolerant check, Bonza).

Relative root length†	Frequency distribution of entries in each class of GSI (%)			Number	% of total
compared with Bonza	0-50%	51-80%	>80%	of entries	entries
Bonza	50.00	46.15	0.00	64	46.72
< Bonza	26.92	15.38	28.57	34	24.82
<< Bonza	23.08	38.46	71.43	39	28.47
Number of entries	104	26	7	137	
% of total entries	75.91	18.98	5.11		

†Root length in B100 relative to B0, compared with B toxicity tolerant check. Bonza = not significantly different from Bonza; <Bonza = significantly shorter at $P = 0.05$; <<Bonza = significantly shorter at $P = 0.01$

Conclusion

Wheat genotypes that are B-efficient were not tolerant to B toxicity. However, those that are B efficient may or may not be tolerant to B toxicity.

Acknowledgements

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