รายงานวิจัยฉบับสมบูรณ์

ความแปรปรวนทางพันธุกรรมของลักษณะการเป็นหมัน เนื่องจากขาดธาตุโบรอนในข้าวบาร์เลย์

โดย

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31 กรกฎาคม 2543

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ชุดโครงการทุนวิจัยหลังปริญญาเอก

FINAL REPORT

GENOTYPIC VARIATION IN BORON DEFICIENCY-INDUCED MALE STERILITY IN BARLEY

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ผู้วิจัยขอขอบคุณ สำนักงานกองทุนสนับสนุนการวิจัยเป็นอย่างสูง ที่ให้ทุนสนับสนุนงานวิจัยหลังปริญญาเอกในครั้งนี้

ขอขอบคุณศูนย์วิจัยเพื่อเพิ่มผลผลิตทางเกษตรและภาควิชาพืชไร่ คณะเกษตรศาสตร์ มหาวิทยาลัยเชียงใหม่ ที่ให้ความอนุเคราะห์ด้านสถานที่ แปลงทดลอง และเครื่องมือวิทยาศาสตร์ที่ใช้ในการวิจัย

เมล็ดพันธุ์ข้าวบาร์เลย์ที่ใช้ในโครงการวิจัยนี้ได้รับการอนุเคราะห์จาก ศูนย์วิจัยการปรับปรุงข้าวโพดและข้าวสาลีนานาชาติ (CIMMYT) คุณสุชีรา มูลศรี สถานีทดลองข้าวไร่และธัญพืชเมืองหนาว สะเมิง กรมวิชาการเกษตร รองศาสตราจารย์สุทัศน์ จุลศรีไกวัล ภาควิชาพืชไร่ คณะเกษตรศาสตร์ มหาวิทยาลัยเชียงใหม่ และ ดร. จันทรวิภา ธนะโสภณ บริษัททีซีซีการเกษตร ขอขอบคุณ คุณสิทธิชัย ลอดแก้ว ศูนย์วิจัยเพื่อเพิ่มผลผลิตทางเกษตร มหาวิทยาลัยเชียงใหม่ ที่ให้ความช่วยเหลือด้านการวิเคราะห์ธาตุโบรอน

บทคัดย่อ

สัญญาเลขที่: PDF/ 74/ 2540

ชื่อโครงการ: ความแปรปรวนทางพันธุกรรมของลักษณะการเป็นหมันเนื่องจากขาดธาตุโบรอนในข้าวบาร์เลย์

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วัตถุประสงค์: เพื่อบ่งชี้และประเมินความแตกต่างทางพันธุกรรมในลักษณะการเป็นหมันเนื่องจากขาดธาตุโบรอน

ขอบเขตการวิจัย: ศึกษาลักษณะการตอบสนองของพันธุกรรมข้าวบาร์เลย์ต่อระดับธาตุโบรอนในสภาพ sand culture และแปลงทดลอง ประเมินขอบเขตของความหลากหลายทางพันธุกรรมในการตอบสนองต่อการขาดธาตุดังกล่าว คัดเลือกสายพันธุ์ที่มีประสิทธิภาพการใช้ธาตุโบรอนแตกต่างกันมาศึกษาเปรียบเทียบและสร้างลูกผสมชั่วที่ 1 ในขั้นสุดท้าย เปรียบเทียบความสามารถของลูกผสมชั่วที่ 1 และสายพันธุ์พ่อแม่เมื่อปลูกในสภาพโบรอนระดับต่างๆ

ผลที่ได้รับ: การขาดธาตุโบรอนทำให้การติดเมล็ดและจำนวนช่อดอกของข้าวบาร์เลย์ลดลงและส่งผลให้ผลผลิตลดตามไปด้วย พบความแตกต่างทางพันธุกรรมในลักษณะประสิทธิภาพการใช้ธาตุโบรอนแต่ข้าวบาร์เลย์ส่วนใหญ่มักมีประสิทธิภาพการใช้ธาตุโบรอนต่ำ อย่างไรก็ตามพบข้าวบาร์เลย์จำนวน 2 สายพันธุ์แสดงประสิทธิภาพการใช้ธาตุโบรอนได้สูง และลักษณะประสิทธิภาพการใช้ธาตุโบรอนสูงนี้ถูกควบคุมโดยพันธุกรรมสามารถถ่ายทอดไปยังรุ่นต่อไปได้

สรุปสาระสำคัญของผลที่ได้จากการวิจัย: พบแหล่งของความแปรปรวนทางพันธุกรรมในลักษณะประสิทธิภาพการใช้ธาตุโบรอนสูงในข้าวบาร์เลย์ สามารถหลีกเลี่ยงปัญหาผลผลิตลดลงเนื่องจากการเป็นหมันเมื่อปลูกในสภาพธาตุโบรอนต่ำๆ ได้โดยการคัดเลือกและปรับปรุงพันธุ์เพื่อประสิทธิภาพการใช้ธาตุโบรอน สายพันธุ์ BRB 9604 และ BRB 9624 สามารถใช้แนะนำปลูกในพื้นที่ที่มีธาตุโบรอนต่ำๆ หรือใช้เป็นสายพันธุ์พ่อแม่ในโครงการปรับปรุงพันธุ์ต่อไป

ข้อเสนอแนะสำหรับงานวิจัยในอนาคต: น่าจะได้มีการศึกษาจำนวนยีนที่ควบคุมประสิทธิภาพการใช้ธาตุโบรอนสูงและตำแหน่งของยีนบนโครโมโซม ความเข้าใจในเรื่องจำนวนยีนจะเป็นประโยชน์ในการตัดสินใจเลือกใช้ชนิดวิธีการคัดเลือกและปรับปรุงพันธุ์เพื่อประสิทธิภาพการใช้โบรอน หากทราบตำแหน่งยีนจะเป็นประโยชน์ในการสร้างแผนที่ยีน ซึ่งจะช่วยเพิ่มประสิทธิภาพในการคัดเลือกโดยใช้ลักษณะหรือยีนบ่งชี้อื่นๆ ที่อยู่ใกล้กันเข้ามาช่วยในการคัดเลือกได้แม่นยำยิ่งขึ้น

คำหลัก: ข้าวบาร์เลย์ ธาตุโบรอน ความแปรปรวนทางพันธุกรรม

Abstract

Project Code:	PDF/ 74/ 2540	
Project Title:	Genotypic variation in boron deficiency-induced sterility in barley	
Investigators:	Dr. Sansanee Jamjod	Chiang Mai University
	Prof. Dr. Benjavan Rerkasem	Chiang Mai University
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Project Period:	1 August 1997- 31 July 2000	
Objectives:	To identify and evaluate genetic variation in boron response in barley.	

Methodology: Boron (B) responses of barley genotypes were identified in sand culture and in the field. Genotypic variation in the response to B was determined. Genotypes with different levels of B efficiency were selected and evaluated. Selected genotypes were also used as parents to produce F_1 hybrids. F_1 hybrids were then evaluated for their response to B, compared to their respective parents.

Results: Grain yield of barley was severely depressed by B deficiency through reduction of grain set and spikelet number. Genotypic variation in B efficiency was identified, with most genotypes fell into the moderately B inefficient and inefficient classes. Two lines were identified as B efficient. Response of F_1 hybrids between B efficient and inefficient genotypes indicated that B efficiency in barley is a heritable trait.

Discussion & Conclusion: Sources of genotypic variation for B efficiency are available in barley. Grain yield reduction caused by sterility under B deficiency can be prevented by selection and breeding for B efficiency. Two advanced lines, BRB 9604 and BRB 9624, may be recommended for low B areas or used as parents in breeding programmes.

Suggestion/ Further Implication/ Implementation: The number of gene(s) controlling B efficiency and their chromosomal locations should be identified. This will assist in determining appropriate strategies for breeding and selecting for B efficiency. Identifying chromosomes controlling B efficiency would help in establishing linkage map, thus allowing a closely linked marker to be identified and used for selection.

Key words: Barley, boron, *Hordeum vulgare*, genotypic variation

1 EXECUTIVE SUMMARY

Project Code: PDF/74/ 2540

Project Title: Genotypic variation in boron deficiency-induced sterility in barley

Investigators: Dr. Sansanee Jamjod — Chiang Mai University

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Project Period: 1 August 1997- 31 July 2000

Objectives: To identify and evaluate genetic variation in boron response in barley.

Yield reduction due to sterility is a major obstacle to expansion of temperate cereals area in Thailand. Boron (B) deficiency has been identified as one of the major causes of sterility. This project set out to evaluate genotypic variation in responses to B. It was found that B deficiency depressed grain number and grain yield in most barley tested. In the most severe case, B deficiency also promoted late tillering but depressed number of spikes plant^{-1} and spikelets spike^{-1}. We have developed an index to measure grain set in barley genotypes, termed Barley Grain Set Index (BGSI). It has been used as a selection criteria for B efficiency. About 300 genotypes from various breeding stations were tested in low B soil and sand culture. A wide range of genotypic variation in responses to B, comparable to that found in wheat, has been found. Sources of B efficiency were identified from two advanced lines, BRB 9604 and BRB 9624, selected in Northern Thailand. At low B soils, grain set and grain yield of these lines were not affected while those of inefficient genotypes were severely depressed. This suggested that these two lines could be recommended in low B areas. BRB 9604 was used to study inheritance of B efficiency by crossing to the moderately inefficient and inefficient genotypes. Response of F_1 hybrids indicated that B efficiency was a heritable trait and non-maternal controlled. B efficiency in F_1 hybrids was expressed within a range from nearly complete dominance to nearly complete recessive depended on cross combination and severity of B deficiency. These findings provide a basis for screening segregating populations in genetic studies and breeding programmes serving low B soils such as Northern Thailand.

2. BACKGROUND AND OBJECTIVES

2.1 Background

Economic importance of barley (*Hordeum vulgare* L.) is indicated by imported value exceeding one billion baht a year. Expansion of barley production is an objective in the National Agricultural Development Plan. However, severe sterility has been observed in barley grown so far in the country. Boron (B) deficiency was identified as the cause of this problem in Chiang Mai, Thailand (Rerkasem and Jamjod, 1989), Finland (Simojoki, 1972) and Malaysia (Ambak and Tadano, 1991). For example, yield of two barley varieties BRB 1 and BRB 2 grown at low B soil in Chiang Mai were reduced more than 50% by B deficiency (Rerkasem and Jamjod, 1989).

A number of studies suggested that B plays a significant role in reproductive development, for example, flower development and fertilization processes. In general, B deficiency symptoms of small grain cereals such as wheat (Rerkasem et al., 1987), barley (Simojoki, 1972) and rice (Garg et al., 1979) were observed on reproductive organ, resulted in grain set failure. Boron deficiency symptom of wheat was described as sterility, which can be seen at anthesis. Florets remain open, resulting in 'gaping glume' in which spikes are transparent appearance when viewed with the sun behind them. The anthers and pollens of these sterile plants were poorly developed (Li et al., 1978; Sthapit, 1988; Rerkasem et al., 1989).

In barley, Simojoki (1972) reported that sterility in barley has been observed when grown in soil with water-soluble B 0.1-0.2 mgL^{-1} and an application of B fertilizer was able to correct the problem. The symptoms of B deficiency in barley were described as an abnormal of pollen and stamen, swelling of ovary, openness of spikelets at early flowering stage. Symptom was more severe on tillers than main stem. The B deficient spikes were proned to be infected by ergot fungus as the ears remain open. Ambak and Tadano (1991) reported that when barley cultivar Hoshimasaii was grown in micronutrient-deficient peat soil, the highest percentage of sterility was caused by B deficiency in this soil and the depression on vegetative was not observed. Rerkasem and Jamjod (1989) reported that the symptoms of B deficiency in two barley cultivars, BRB 1 and BRB 2, were observed only as sterility of the cars but not on the vegetative part when grown in soils

with hot water soluble B at 0.13 mg kg^{-1}. However, when grown in nutrient solution, Nable et al. (1990) reported that B deficiency symptom of barley can be observed on leaf blades, described as wrinkled, mishapen, irregularly chlorotic and occasionally had split margins "saw-tooth edges" and longitudinal splits.

Genotypic variation for response to low B has been reported in several crops (Rerkasem and Jamjod, 1997) suggesting that the widespread B deficiency in barley could be managed by growing B efficient cultivars. In wheat, Jamjod et al. (1992a) screened germplasm originating from CIMMYT and adapted to northern Thailand, were among the most B efficient. Further screening has established the response to low B when tested in sand culture without add B compared to add B. Altogether, 252 genotypes, collected from Thailand, Bangladesh, Nepal, China, India, South America, Australia and CIMMYT, were screened and classified into five distinctive classes including very inefficient, inefficient, moderately inefficient, moderately efficient and efficient. In this screening only nine genotypes, seven from Thailand and two from China and India each were identified as B efficient (Rerkasem and Jamiod, 1997). At very low B the very inefficient genotypes were completely sterile while the B efficient genotypes set grain normally.

Genetic control of response to B deficiency has been studied for a number of species. Response to B deficiency in celery (Pope and Munger, 1953), tomato (Wall and Andrus, 1962) and red beet (Tehrani et al., 1971) was reported to be under monogenic control. However, Kelly and Gabelman (1960) found that the genetic control of B efficiency in table beets was complex. In sunflower, Blamey et al. (1984) found that general combining ability effects were significant for the concentration of B in leaf, deficiency symptom and grain yield. These three characters were highly heritable and additive or additive epistatic gene action predominated. In genetic studies with two crosses between B inefficient x B efficient wheat genotypes, broadsense and narrow sense heritability for B efficiency were 0.50-0.58 and 0.35-0.42, respectively (Jamjod et al., 1992b), suggested a high possibility of breeding and selection for B efficiency trait in this crop.

In contrast to wheat, there is no information of genetic variation in response to low B in barley. Extensive studies with the mechanism and genetics of response to B in barley have been done with B toxicity (Nable et al., 1997). As barley is becoming an important crop to agricultural and industrial production of Thailand, it is therefore important to study the incident of B deficiency-induced sterility in this crop. Understanding genotypic

variation in B efficiency and its inheritance will assist in breeding and selection for B efficient varieties to grow in problem areas

2.2 Objectives

The objective of this project was to increase yield of barley by preventing sterility through breeding and selection for B efficiency when grown in low B areas through:

- Identification of genetic variation and source of B efficiency;
- Development of screening procedures for large number of genotypes;
- Identification of inheritance for B efficiency.

3. MATERIALS AND METHODS

3.1 Sand culture experiments

In sand culture plants were grown in freely drained earthenware pots (30cm diameter and 30cm deep) or trays (45cm x 70cm x 35cm) contained washed river quartz sand with no detectable available B. The sand was watered twice daily with an otherwise complete nutrient solution (Table 3.1) with varying levels of boron supply (0, 0.1 or 1.0 μM B, designated as B0, B0.1 and B1.0, respectively) in three replications. The pots/trays were flushed with water once every 4-5 weeks.

Table 3.1. Nutrient solution for sand culture.[a]

Stock solution	Element	Salt	G/l	M	μM
1	Ca	$CaCl_2.2H_2O$	294.1	2.0	1000
2	P	KH_2PO_4	136.1	1.0	500
3	Fe	Fe-Citrate	6.7	0.02	10
	Mg	$MgSO_4.7H_2O$	123.3	0.5	250
	K	K_2SO_4	87.0	0.5	250
	Mn	$MnSO_4.H_2O$	0.338	0.002	2
4	Zn	$ZnSO_4.7H_2O$	0.288	0.001	0.5
	Cu	$CuSO_4.5H_2O$	0.100	0.0004	0.2
	Co	$CoSO_4.7H_2O$	0.056	0.0002	0.1
	Mo	$Na_2MoO_2.2H_2O$	0.048	0.002	0.1
5	N	KNO_3	101.0	1.0	5000
6	B	H_3BO_3	0.247	0.004	2

Boron free:

For each 10 litres of full strength nutrient solution, take 5.0 ml each of solutions 1 to 4, 50 ml of solution 5, dilute to 10 litres with water. Adjust pH to 6.6-6.8 with NaOH or HCL

With Boron:

Adding 5.0 ml of solution 6 as well as 5 ml of solution 1 to 4 and 50 ml of solution 5 to make 10 litres of nutrient solution will give boron concentration of 2 μM or 0.02 ppm.

[a] Adapted from Broughton and Dilworth (1971).

Response of genotypes were assessed at two harvesting times; at booting stage for flag leaf B concentrations and at maturity stage for number of spikes plant^{-1}, spikelets spike^{-1}, grains spikelet^{-1}, 100 seed weight (100SW), straw yield and grain yield.

3.2 Field experiments

Field experiments were carried out in the field on low B sandy loam (hot water soluble boron at 0.10-0.14 mg B kg^{-1}) soil at Multiple Cropping Center, Chiang Mai University in 1997/98 and 1998/99 growing seasons. Boron treatments were varied into four levels by applying either lime or B to the soil before sowing, designated as follow:

BL: plus 1.6 t of lime ha^{-1}

B0: nil

B1: 1 kg Borax ha^{-1}

B2: 10 kg Borax ha^{-1}

The experiments were arranged in split-plot design with four replications. Boron treatments were arranged as mainplot and genotypes as subplot. In each plot, genotypes were sown in three, 2-m row with 25 cm between rows. At early boot stage, twenty spikes of each plot were bagged to prevent outcrossing. At maturity, the bagged spikes were harvested separately and determined for number of spikelets spike^{-1}, grains spike^{-1}, grains spikelet^{-1} and grain set. Grain yield was measured from the remaining spikes in the three-row plot.

3.3 The Barley Grain Set Index

The effect of B on grain set in wheat was measured as the Grain Set Index (GSI), which is defined as the percentage of the twenty basal florets from ten central spikelets on a spike with grain (Rerkasem and Loneragan, 1994). In the present study with barley, the term Barley Grain Set Index (BGSI) was used in order to distinguish it from the GSI used in wheat. BGSI was defined as;

- percentage of the ten median spikelets on the central of a spike with grain for two-row barley, and
- percentage of the twenty lateral spikelets on the central of a spike with grain for six-row barley

3.4 Genotypes

(1) Two barley and one wheat genotypes in sand culture with three B levels in 1997/98.
(2) 21 entries from the Barley Thailand Yield Nurseries 97/98, in sand culture with B0.
(3) 9 advanced barley lines/locally adapted varieties in the field with three B levels in 1997/98.
(4) 244 barley lines from the International Barley Yield Trial (IBYT 98/99, 219 entries) and International Barley Observation Nursery (IBON 98/99, 25 entries), in sand culture with B0 in 1998/99.
(5) Wheat genotypes with known levels of B response were included as checks in all experiments except (1).

3.5 F_1 production and evaluation

Parents with contrasting levels of response to B were chosen from 3.4 (2). Crossing plots were conducted in the field in 1998/99 with four sowing dates, to synchronize flowering time. In each plot, four 2-m rows of each parental line were grown with a spacing of 30 cm between row. Hand emasculation of spike form the female parent was performed at booting stage and then bagged to prevent cross-pollination. Three days after emasculation, the bagged spikes were pollinated with pollen from the male parent by swirling method (Starling, 1980). Ten to twenty spikes from each cross combination were made. At maturity, spikes were harvested separately and kept at 4 °C until used.

F_1 hybrids were tested for response to B and compared to their parents in sand culture in 1999/2000 in two experiments. In Experiment 1, two crosses namely, BRB 9604 x BRB 9 and BRB 9 x BCMU 96-9, and their reciprocal crosses were evaluated in two levels of B, 0 μM B (B0) and 10 μM B (B10). Ten plants of F_1 hybrid or parent were grown in each pot without replication. Data were recorded for number of tillers plant^{-1} every five days. At maturity, number of spikes plant^{-1}, spikelets spike^{-1}, grains spikelets^{-1} and BGSI were measured from every tiller. In Experiment 2, crosses between the most B efficient barley, BRB 9604 and four lines, BRB 9, BCMU 96-9, Stirling and SMGBL 94003 were evaluated in four levels of B (0, 0.1, 1.0 and 10.0 μM B) in sand culture. Parents and their F_1 hybrid from each combination were sown in the same pot with two replications. At maturity, BGSI, number of grains spikelet^{-1} and spikelets spike^{-1} were determined.

4. RESPONSE OF BARLEY TO BORON DEFICIENCY

4.1 Visual symptoms

Foliar symptom

Symptom of boron deficiency on morphological character was not observed when barley genotypes were grown in the field and in sand culture in 1997/98 and 1998/99. However, in 1999/2000 foliar symptom was observed on younger leaves of Stirling barley grown in sand culture at B0 that was similar to those described by Robson and Snowball (1986) and Nable et al. (1990). The symptom was observed as the splitting of the newer leaves along the leaves close to the midrib (i.e. saw-tooth edges). Leaf blades were wrinkled, mishapen and chlorotic. These symptoms were not observed in any wheat genotypes tested in this study.

Spike

An abnormal of spike development was observed in exotic, advanced lines of barley introduced from CIMMYT when grown in sand culture at B0 in1998/99. The spikes were emerged but deaths of spikelets at the tip were observed. In Cu-deficient wheat, rat-tail spikes were observed with full grain in the base of the spike, shriveled grains in the middle of the head and a withered necrotic tip (Robson and Snowball, 1986). The symptom found in barley was differed from that in the Cu-deficient wheat as the spikelets adjacent to those which die grow normally but no grain was set in any spikelets of the B-deficient spike. In the present study, six-row barley tended to have higher number of accessions exhibiting abnormal spikes than two-row barley (Table 4.1.1). This symptom was not observed in bread wheat.

Table 4.1.1 Number of barley lines (% of 244 lines) exhibited normal and abnormal spikes when tested in B0. Sand culture screening 1997/98.

Spike type	Normal spike	Abnormal spike
Two-row barley	89	11
Six-row barley	28	72

4.2 Yield and yield components

Boron deficiency has been reported to affect grain yield of wheat through grain set (Rerkasem et al., 1987). The present study in barley was consistent to that found in wheat. In sand culture experiment, it was found that under B deficiency (0 μM B) grain yield of BRB 2 and Stirling were severely depressed (Table 4.2.1) at the rate similar to SW 41 wheat. Straw yields of BRB 2 and SW 41 were not effected by B deficiency but that of Stirling was reduced significantly. Grain yield of all genotypes was depressed by B deficiency through grain set i.e. grains spikelets^{-1} and GSI (Figures 4.2.1 and 4.2.2). Moreover, in Stirling, B deficiency also depressed spikes plant^{-1} and spikelets spike^{-1}.

Table 4.2.1 Effects of B treatments on (a) grain yield and (b) straw yield of barley and wheat genotypes. Sand culture experiment 1997/98. (Jamjod and Rerkasem, 1999).

Genotype	B treatments[b] (μM)		
	0	0.1	1.0
(a) Grain yield (g pot^{-1})			
Stirling	2.6 a	6.2 a	19.0 b
BRB 2	7.3 a	9.5 a	25.6 b
SW 41	24.8 a	29.2 a	36.9 b
F-test[a] B***, G***, B x G^{ns}			
b) Straw yield (g pot^{-1})			
Stirling	88.9 a	96.3 ab	115.9 b
BRB 2	79.7 a	101.2 a	82.2 a
SW 41	78.5 a	70.9 a	64.5 a
F-test B^{ns}, G***, B x G**			

[a] ** and *** Significant at 0.01 and 0.001 probability levels, respectively; ^{ns} not significant.

[b] Means within a row with the same letter do not differ significantly at 5% level with Dancan's Multiple Range Test.

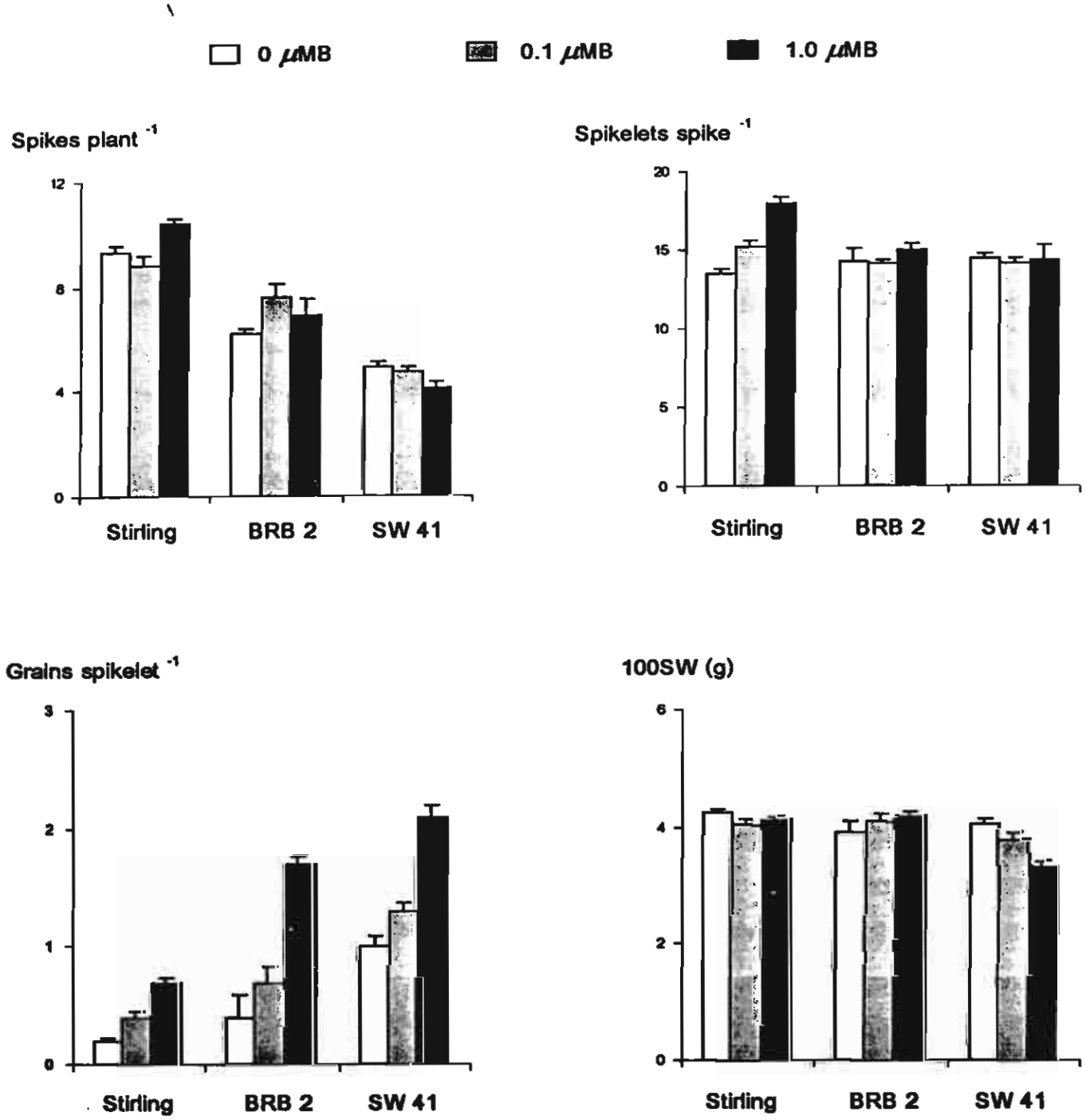


Figure 4.2.1 Effects of B treatment on yield components of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture with 0, 0.1 and 1.0 μM B. Sand culture experiment 1997/98. (Jamjod and Rerkasem, 1999).

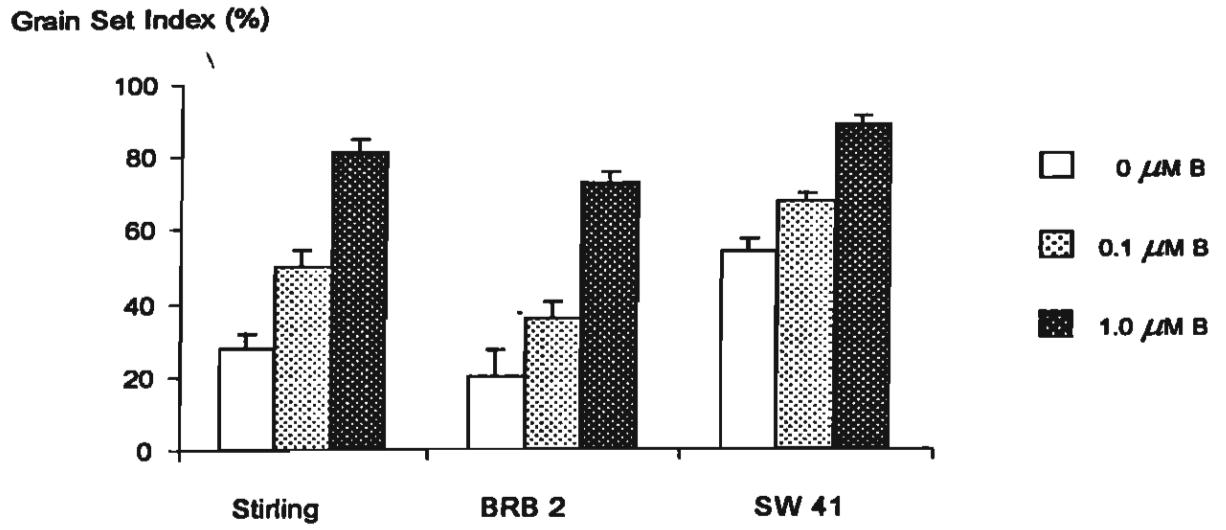


Figure 4.2.2 Effects of B treatment on Grain Set Index (GSI, %) of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture with 0, 0.1 and 1.0 μM B. Sand culture experiment 1997/98. (Jamjod and Rerkasem, 1999).

Grain Set Index (GSI) has been used successfully in wheat to compare the effect of B to grain set, as this criteria discriminates effects of B on grain set from those on grain filling (Rerkasem and Loneragan, 1994; Anantawiroon et al., 1997). As found in wheat, GSI of barley responded positively to external B levels and closely correlate to grain yield (Table 4.2.2). Highly significant correlation of GSI with grains spike^{-1}, grains spikelet^{-1} and grain yield was shown under low B levels. At high B level, GSI did not correlated with grains spike^{-1} and grain spikelet^{-1}, which indicates the dependence of GSI on B levels. The term GSI, generally, refers to the fertility percentage of ten central spikelets of barley or wheat. Since the structure of barley spikes is different from that of wheat, and two-row barley is also different from six-row barley. It is recommended that the term "Barley Grain Set Index" or BGSI, defined as percentage of the ten central spikelets (ten median spikelets for two-row barley and twenty lateral spikelets for six-row barley) on a spike with grains, should be used in order to distinguish it from the GSI used in wheat.

Table 4.2.2 Correlation coefficient (*r*) between Grain Set Index (GSI) or grain yield (italics) and yield components. Sand culture experiment 1997/98. (Jamjod and Rerkasem, 1999).

B treatment		Spikelets spike^{-1}	Grains spike^{-1}	Grains spikelet^{-1}	100SW	GSI
0 μM	GSI	0.11	0.89**	0.89**	0.38	-
	Grain yield	*0.27*	*0.88***	*0.87***	*0.09*	*0.81***
0.1 μM	GSI	0.01	0.72**	0.70**	-0.49*	-
	Grain yield	*-0.23*	*0.80***	*0.89***	*-0.48**	*0.75***
1.0 μM	GSI	0.13	0.37	0.29	-0.64**	-
	Grain yield	*-0.08*	*0.79***	*0.68***	*-0.49**	*0.65***

* and ** Significant at the 0.05 and 0.01 probability levels, respectively.

4.3 Boron in flag leaf

At boot stage, flag leaf B concentrations were increased with increasing B levels (Figure 4.3.1). At low B, both barley and wheat contained >2-4 mg B kg^{-1} and increased to >4-8 mg B kg^{-1} at B 1.0 M. The present results are consistent with previous studies (Rerkasem and Loneragan, 1994; Simojoki, 1972). Flag leaf B concentration can be used as a general indicator for B status in barley and concentrations <4 mg B kg^{-1} appear to predict a decline in grain set from B deficiency.

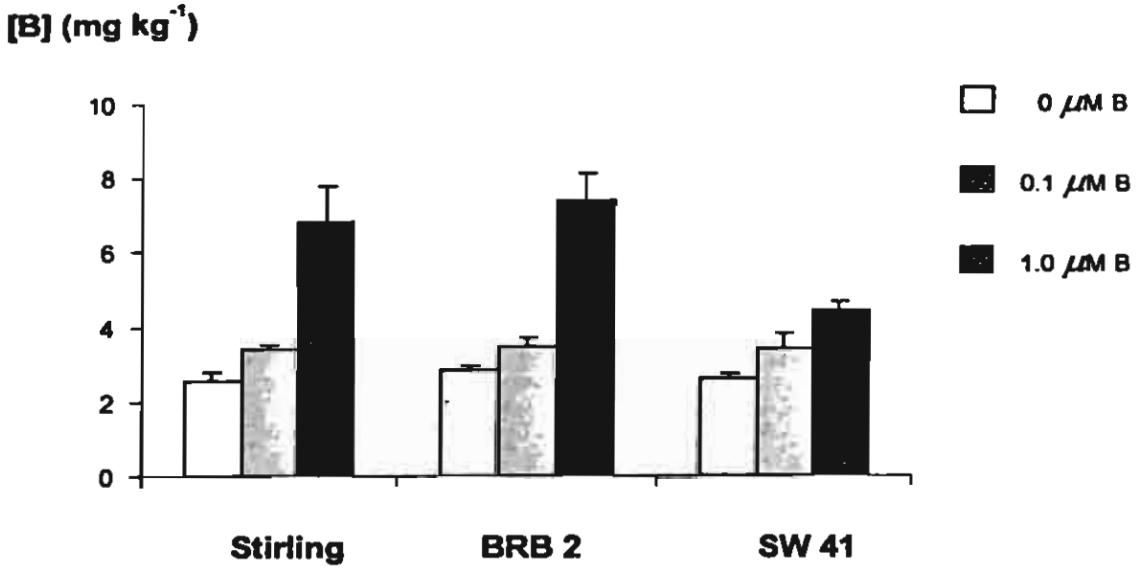


Figure 4.3.1 Effects of B treatment on flag leaf B concentration (mg B kg^{-1}) of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture with 0, 0.1 and 1.0 µM B. Sand culture experiment 1997/98. (Jamjod and Rerkasem, 1999).

5 GENOTYPIC VARIATION IN BORON EFFICIENCY IN BARLEY

5.1 Evaluation of advanced lines

Field experiment was carried out in 1997/98 to evaluate B responses of 9 locally adapted, advanced lines or cultivars of barley. The objectives are to identify the genotypic range of B responses within these 9 genotypes and to identify specific response which may be used in further study or breeding programmes. Barley genotypes were grouped into two-row and six-row classes. Boron efficient (Fang 60) and moderately inefficient (SW 41) wheat genotypes were included as checks. Genotypes differed significantly in response to B in spikelets spike^{-1}, grains spike^{-1}, grains spikelets^{-1} and BGSI (Table 5.1.1-5.1.4).

Boron had no effect on number of spikelets of all six-row barley genotypes, as well as wheat checks, Fang 60 and SW 41 (Table 5.1.1). However, the number of spikelets spike^{-1} of three two-row barleys, namely, Stirling, SMGBL 91002 and SMGBLS 94003, showed clear positive responses to increasing B.

Very significant interaction between B treatments and genotypes was observed on grains spike^{-1} (Table 5.1.2), grains spikelet^{-1} (Table 5.1.3) and GSI (Table 5.1.4). Grains spike^{-1} and grains spikelet^{-1} of SW 41, the B inefficient check and most barley genotypes were lowest in the BL treatment and increased with increasing B, whereas those of Fang 60 remained constant.

When all genotypes were compared using GSI (Table 5.1.4), they can be classified into four different groups. Fang 60 wheat was the most efficient genotype and had more than 90% GSI in all B treatments. CMBL 92029, BRB 9, SMGBLS 91002, SMGBLS 94003, BCMU 96-5 and BRB 2 had low GSI similar to SW 41 and were classed as inefficient to B. The GSI of BCMU 96-9 and BCMU 96-1 at BL and B0 were intermediate between those of SW 41 and Fang 60. Stirling was the most inefficient genotypes, its GSI was 19, 23 and 79% in BL, B0 and B+ respectively.

Table 5.1.1 Effect of B treatments on spikelets spike^{-1} of barley and wheat genotypes. Field experiment 1997/98. (Jamjod and Rerkasem, 1999).

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	22.2 a	23.8 a	22.9 a
BRB 9	14.6 a	14.0 a	13.3 a
CMBL 92029	17.9 a	19.7 a	20.5 a
SMGBLS 91002	21.4 a	23.3 ab	25.0 b
SMGBLS 94003	21.5 a	24.4 b	23.8 ab
Stirling	15.6 a	18.5 b	19.4 b
Six-row barley			
BCMU 96-1	18.9 a	18.5 a	16.8 a
BCMU 96-5	15.7 a	18.5 a	16.9 a
BRB 2	17.0 a	18.4 a	16.5 a
Wheat			
Fang 60	13.2 a	13.9 a	12.8 a
SW 41	14.6 a	15.4 a	15.6 a
F-test[a]	B^{ns}, G**, BxG*		

[a] * and ** Significant at 0.05 and 0.01 probability levels, respectively; ^{ns} not significant.

[b] Mean within a row with the same letter do not differ significantly at 5% level with Dancan's Multiple Range Test.

Note: B treatments are BL = plus 1.6 t lime ha^{-1}, B0 = nil and B+ = plus 10 kg Borax ha^{-1}

Table 5.1.2 Effect of B treatments on grains spike^{-1} of barley and wheat genotypes. Field experiment 1997/98. (Jamjod and Rerkasem, 1999).

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	12.1 a	18.3 a	19.1 a
BRB 9	6.6 a	7.9 a	11.7 a
CMBL 92029	8.1 a	6.0 a	12.2 a
SMGBLS 91002	3.6 a	10.1 ab	18.5 b
SMGBLS 94003	5.8 a	10.7 ab	16.4 b
Stirling	2.6 a	3.8 a	11.3 b
Six-row barley			
BCMU 96-1	30.8 a	38.6 ab	41.0 b
BCMU 96-5	18.0 a	30.0 b	40.3 c
BRB 2	23.5 a	34.0 b	36.6 b
Wheat			
Fang 60	36.3 a	39.0 a	33.0
SW 41	14.8 a	19.0 a	34.2 b
F-test[a] B**, G**, BxG**			

[a] ** Significant at 0.01 probability level.

[b] Mean within a row with the same letter do not differ significantly at 5% level with Dancan's Multiple Range Test.

Note: B treatments are BL = plus 1.6 t lime ha^{-1}, B0 = nil and B+ = plus 10 kg Borax ha^{-1}

Table 4.1.3 Effect of B treatments on grains spikelet^{-1} of barley and wheat genotypes. Field experiment 1997/98. (Jamjod and Rerkasem, 1999).

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	0.5 a	0.8 a	0.8 a
BRB 9	0.5 a	0.6 a	0.9 a
CMBL 92029	0.4 a	0.3 a	0.6 a
SMGBLS 91002	0.2 a	0.4 ab	0.7 b
SMGBLS 94003	0.3 a	0.4 a	0.7 a
Stirling	0.2 a	0.2 a	0.6 b
Six-row barley			
BCMU 96-1	1.6 a	2.1 ab	2.4 b
BCMU 96-5	1.1 a	1.6 b	2.4 c
BRB 2	1.4 a	1.8 ab	2.2 b
Wheat			
Fang 60	2.7 a	2.8 a	2.6 a
SW 41	1.0 a	1.2 ab	2.2 b
F-test[a]	B**, G**, BxG**		

[a] ** Significant at 0.01 probability level.

[b] Mean within a row with the same letter do not differ significantly at 5% level with Dancan's Multiple Range Test.

Note: B treatments are BL = plus 1.6 t lime ha^{-1}, B0 = nil and B+ = plus 10 kg Borax ha^{-1}

Table 4.1.4 Effect of B treatments on Grain Set Index (%) of barley and wheat genotypes. Field experiment 1997/98. (Jamjod and Rerkasem, 1999).

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	65.6 e	84.2 de	91.2 ab
BRB 9	48.1 cde	61.5 bc	90.5 ab
CMBL 92029	42.3 bcd	33.0 a	67.3 a
SMGBLS 91002	27.0 ab	61.5 bc	92.8 b
SMGBLS 94003	36.4 abc	55.8 bc	85.4 ab
Stirling	19.0 a	23.1 a	79.1 ab
Six-row barley			
BCMU 96-1	60.1 de	74.4 cd	89.1 ab
BCMU 96-5	43.9 bcd	63.8 bcd	86.6 ab
BRB 2	40.5 bcd	71.9 bcd	83.4 ab
Wheat			
Fang 60	94.4 f	97.0 e	96.6 b
SW 41	42.7 bcd	52.5 b	93.0 b
F-test[a]	B**, G**, BxG**		

[a] ** Significant at 0.01 probability level.

[b] Mean within a row with the same letter do not differ significantly at 5% level with Dancan's Multiple Range Test.

Note: B treatments are BL = plus 1.6 t lime ha^{-1}, B0 = nil and B+ = plus 10 kg Borax ha^{-1}

5.2 Evaluating germplasm for B efficiency

Very limited genotypic variation for B efficiency was found within germplasm introduced from oversea. Without B added to the nutrient solution, none of advanced lines of barley from the International Barley Nurseries (IBON + IBYT) was B efficient. More than 90% of these germplasms were classified as B inefficient (GSI <20) and 6% were similar to or less than the moderately in check efficient (Table 5.2.1). In contrast, genotypic variation for B response within advanced lines selected in Thailand was demonstrated with 10% of barley lines from the National nurseries (BTYN97/98) exhibited GSI in the range of 81-100%.

Table 5.2.1 Grain Set Index in advanced lines from Barley Thailand Yield Nurseries (BTYN) and International Barley Nurseries (IBON + IBYT) in sand culture without added B. Sand culture screening 1997/98 and 1998/99.

Nursery[a]	Total tested	GSI				
		0-20	21-40	41-60	61-80	81-100
		Number of lines (%)				
BTYN97/98	21	5	24	29	33	10
IBON 98/99 + IBYT 98/99	244	94	4	2	0	0

Note: GSI of Fang 60 (B efficient) and SW 41 (moderately B inefficient) wheat checks were 95-98% and 65-71%, respectively.

[a] BTYN 1997/98 = Barley Thailand Yield Nurseries 97/98, IBON = International Barley Observation Nursery 1998/99 and IBYT = International Barley Yield Trail 1998/99

Within the BTYN 97/98, the GSI of two genotypes were in the range of 81-100% (Table 5.1.2). However, only BRB 9604 set grain better than SW 41 and comparable to Fang 60, and was classified as B efficient. The remaining lines set grain either similar to or less than the moderately inefficient check, with the exception of BRB 9624 and BRB 9. These two lines were intermediate between the two wheat checks.

Considerable genotypic variation in B efficiency was observed within advanced lines of barley screened in soil and sand culture. BGSI of five lines were higher than the

Table 5.2.2 Response of advanced lines from Barley Thailand Yield Nurseries 1997/98 tested in sand culture with B0. Sand culture screening 1997/98. (Jamjod and Rerkasem, 1999).

Line	Origin[a]	GSI (%)	% of checks	
			Fang 60	SW 41
Two-row barley				
BRB 9604	BRB	90.0	91	138 *
BRB 9624	BRB	85.3	87	131
BRB 9	BRB	79.9	81	123
BRB 9609	BRB	75.2	76 *	115
BRB 10	BRB	74.5	76 *	114
BRB 11	BRB	72.5	74 *	111
LARTC-BL9101 (4)	LMP	64.1	65 **	98
BRB 9621	BRB	61.5	62 **	94
LARTC-BL9119 (11)	LMP	60.7	62 **	93
LARTC-BL9408	LMP	47.9	49 ***	73
SMGBL 94026	SMG	42.3	43 ***	66 *
LARTC-BL9410	LMP	40.4	41 ***	62 *
SMGBL 94003	SMG	4.8	5 ***	8 ***
Six-row barley				
FNBL 8309-34-SMG-1-1	SMG	55.2	56 ***	85
FNBL 8306-BC-SMG-1-1	SMG	46.5	47 ***	71
FNBL #140	SMG	45.9	47 ***	70
FNBL 8404-4-SMG-1-1-1	SMG	38.9	40 ***	60 **
FNBL 8403-6-SMG-1-2-1	SMG	37.0	38 ***	57 **
FNBL 8403-17-SMG-1-1-1	SMG	34.5	35 ***	53 **
SMG 1	SMG	31.9	32 ***	49 **
BRB 2	BRB	24.7	25 ***	38 ***
Wheat (checks)				
Fang 60		98.3	100	151 ***
SW 41		65.1	66 **	100

[a] BRB = Boon Rawd Brewery Co. Ltd; LMP = Lampang Agricultural Research Training Center; SMG = Samoeng Upland Rice and Temperate Cereals Experiment Station.

*, ** and *** Significantly different from check cultivars at $p < 0.05$, 0.01 and 0.001, respectively.

moderately B inefficient wheat, SW 41 (Tables 5.1.4 and 5.2.2). All lines were selected in Northern Thailand, where B deficiency has been reported in wheat and some barley lines (Rerkasem and Jamjod, 1989). The majority of segregating populations and advanced lines used in barley breeding programmes in Thailand were obtained through CIMMYT. Substantial numbers of B efficient wheat lines have been identified from CYMMYT materials (Jamjod et al., 1992a) and the same may be true for barley. It is likely that B efficiency in barley is already available in these germplasms. However, the present results have screened only a small selection of the total variation for all barley. Further screening of germplasms from other sources is required to define the full range of B response for barley.

5.3 Evaluation of genotypes difference in B efficiency

Four selections of two-row, six-row barley and wheat each were tested in the soil with four levels of B. The wheat genotypes represented the whole range of response to B, including, Fang 60 (efficient, E), CMU 88-9 (moderately efficient, ME), SW 41 (moderately inefficient, MI) and Bonza (inefficient, I).

When tested in the soil, B levels had no effect on number of spikelets of all barley and wheat genotypes tested (Table 5.3.1). Genotypes displayed differential number of spikelet spike^{-1}. BCMU 96-9 exhibited the highest number of spikelets spike^{-1}.

Very significant interaction between B treatments and genotypes were observed for grains spike^{-1} (Figure 5.3.1), grains spikelet^{-1} (Figure 5.3.2), GSI (Figure 5.3.3) and grain yield (Figure 5.3.4). Grain set and grain yield of CMU 88-9, SW 41, Bonza, SMGBL 91002, BCMU 96-9, SMG 1, BCMU 96-1 and BRB 2 were reduced by B deficiency while those of Fang 60, BRB 9624, 9604 and FNBL 8309 were not adversely affected.

Grain Set Index was used to classify response to B of the tested barley compared to the wheat checks. Within the checks, Fang 60 was rated as the most B efficient, CMU 88-9 as moderately efficient, SW 41 as moderately inefficient and Bonza as inefficient (Figure 5.3.3). Compared to checks, barley genotypes were classified into three groups as follow: a) BRB 9624, BRB 9604 (two row) and FNBL 8309 (six-row) barley genotypes expressed

similar responses to B as Fang 60 wheat, and being classified as B efficient; b) SMGBL 91002 (two row, BCMU 96-1 and BRB 2 (six-row) showed the same responses as SW 41 wheat and were classified as moderately B inefficient; and c) BCMU 96-9 (two-row) and SMG 1 (six-row) showed the same responses Bonza wheat and were classified as B inefficient.

Table 5.3.1 Effect of B treatments on spikelets spike^{-1} of selected two-row and six-row barley, and wheat genotypes. Field experiment 1998/99. (Jamjod et al., 2000).

Genotype[a]	B treatments				Mean
	BL	B0	B1	B2	
Two-row barley					
BRB 9624	14.2	14.9	15.6	15.5	15.0 b
BRB 9604	16.5	15.9	15.6	15.9	16.0 cd
SMGBL 91002	21.1	24.1	25.5	24.6	21.2 f
BCMU 96-9	23.8	24.1	25.5	24.6	24.5 g
Six-row barley					
FNBL 8309	13.6	13.0	13.6	13.2	13.3 a
SMG 1	14.4	14.9	15.4	15.0	14.9 b
BCMU 96-1	17.7	17.1	18.2	17.5	17.6 e
BRB 2	16.2	16.9	17.1	16.5	16.7 d
Bread wheat					
Fang 60	15.0	15.8	16.6	15.8	15.0 bcd
CMU 88-9	16.4	16.1	17.2	15.7	16.4 d
SW 41	17.3	17.2	18.8	17.6	17.7 e
Bonza	15.1	14.7	16.5	15.4	15.4 bc

F-test: B^{ns}, G***, BxG^{ns}; *** Significant at $p< 0.001$

[a] Mean within a column with different letters are differ significantly at $p = 0.05$ with LSD.

Note: B treatments are BL = 1.6 t lime ha^{-1}, B0 = nil, B1 = 1.0 kg Borax ha^{-1} and B2 = 10 kg Borax ha^{-1}.

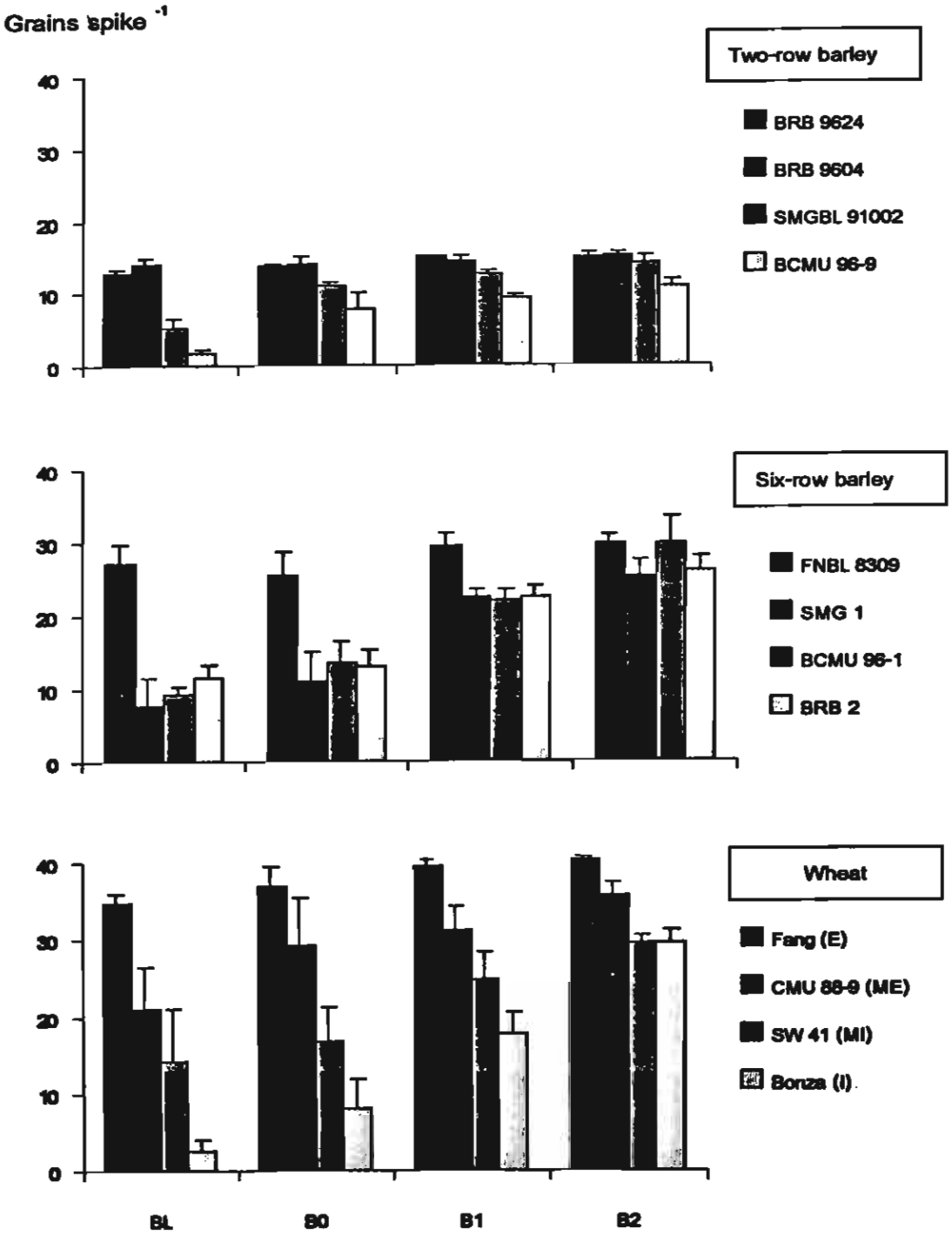


Figure 5.3.1 Effect of B treatment (B) on number of grains spike^{-1} of barley and bread wheat genotypes (G). B x G significant at $p<0.001$, LSD (0.05) = 6.5. B treatments are BL = 1.6 t lime ha^{-1}, B0 = nil, B1 = 1.0 kg Borax ha^{-1} and B2 = 10 kg Borax ha^{-1}. Field experiment 1998/99. (Jamjod et al., 2000).

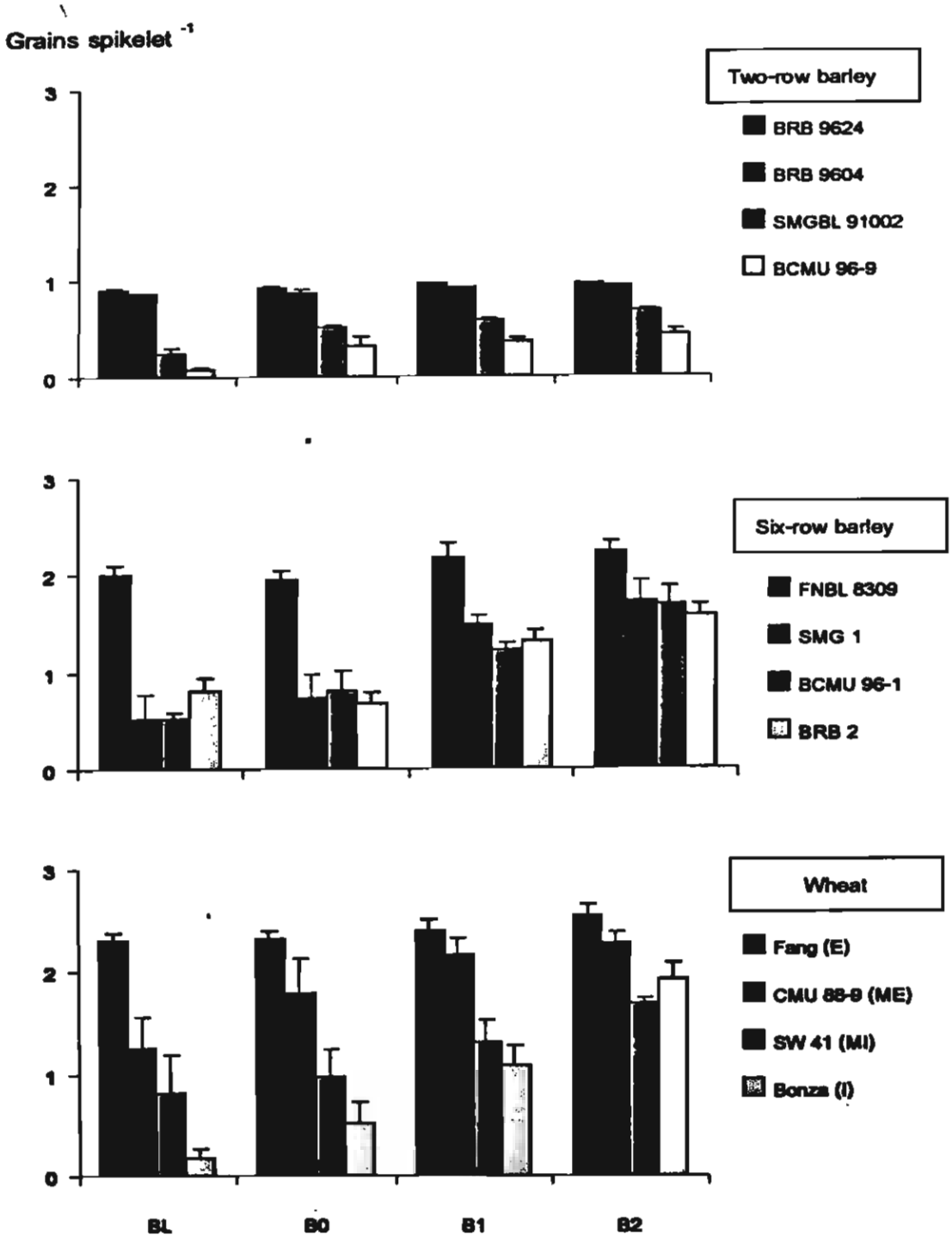


Figure 5.3.2 Effect of B treatment (B) on number of grains spikelet^{-1} of barley and bread wheat genotypes (G). B x G significant at $p<0.001$, LSD (0.05) = 0.4. B treatments are BL = 1.6 t lime ha^{-1}, B0 = nil, B1 = 1.0 kg Borax ha^{-1} and B2 = 10 kg Borax ha^{-1}. Field experiment 1998/99. (Jamjod et al., 2000).

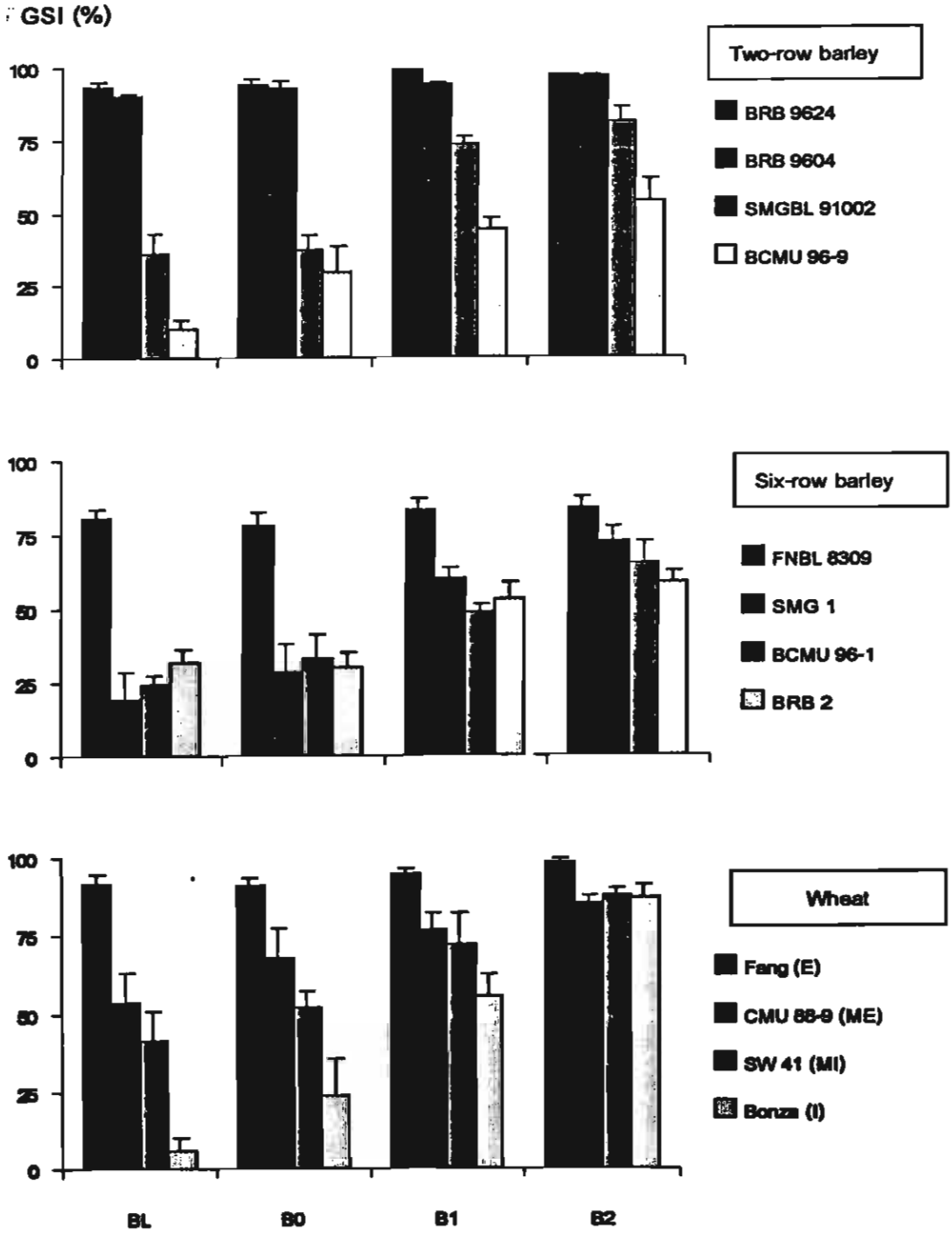


Figure 5.3.3 Effect of B treatment (B) on number of Grain Set Index, GSI (%) of barley and bread wheat genotypes (G). B x G significant at $p<0.001$, LSD (0.05) = 16.9. B treatments are BL = 1.6 t lime ha^{-1}, B0 = nil, B1 = 1.0 kg Borax ha^{-1} and B2 = 10 kg Borax ha^{-1}. Field experiment 1998/99. (Jamjod et al., 2000).

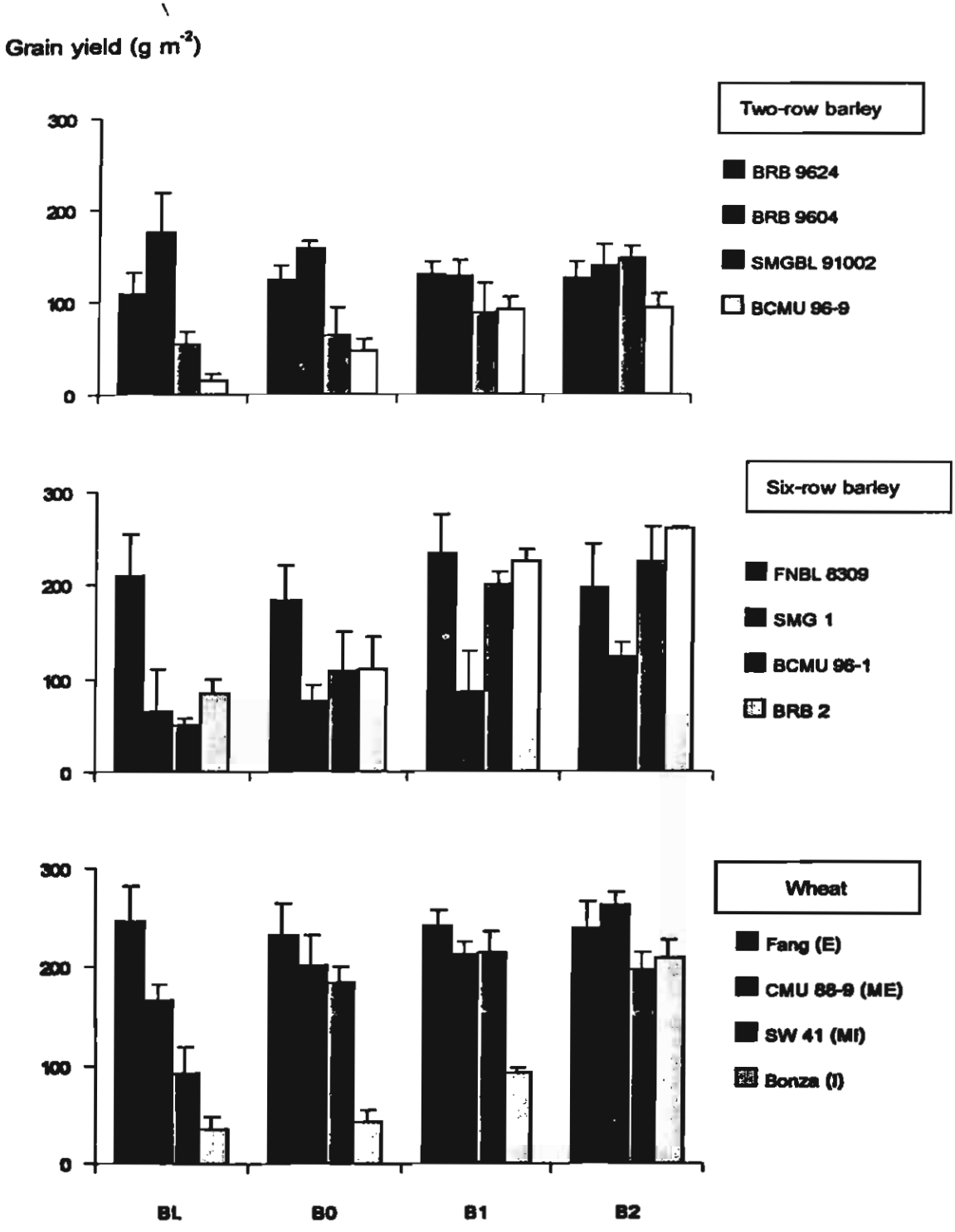


Figure 5.3.4 Effect of B treatment (B) on number of grain yield (g m^{-2}) of barley and bread wheat genotypes (G). B x G significant at $p<0.001$, LSD (0.05) = 6.5. B treatments are BL = 1.6 t lime ha^{-1}, B0 = nil, B1 = 1.0 kg Borax ha^{-1} and B2 = 10 kg Borax ha^{-1}. Field experiment 1998/99. (Jamjod et al., 2000).

Genotypic variation for response to B within advanced lines of barley selected in Thailand was confirmed by these results. Two advanced lines, namely, BRB 9624 and BRB 9604, selected from the previous screening (Table 5.2.2) exhibited normal grain set and grain yield under B deficiency conditions. These lines can be recommended for barley production in low B areas. Moreover, they may be used to introduce B efficiency to the commercial cultivars by breeding.

Response to B of FNBL 8309 in this study contrasted with previous screening. In 1997/98 screening, this line displayed the highest GSI with the six-row barley tested but was rated as moderately B inefficient as SW 41 when tested in sand culture (Table 5.2.2). However, when tested in the soil, FNBL 8309 revealed the same level of B efficiency as Fang 60. Mechanism of B uptake when plants were grown in soils may be different from in sand culture or nutrient solution (Marschner, 1995). Boron efficiency of FNBL 8309 should be confirm before being recommended to farmers or used in breeding programmes.

Boron efficiency barley genotypes were identified among advanced lines derived from CIMMYT germplasm, selected and evaluated in Northern Thailand. This was consistent to that found in bread wheat that B efficient genotypes were identified from advanced lines originating from CIMMYT materials and selected in Thailand such as Fang 60 and #144 (Rerkasem and Jamjod, 1997). This suggests that low B in this region may have acted as a selection pressure upon the adaptation of these genotypes. Although sources of B efficiency are available in this germplasm, it was shown that very low frequency of advanced lines in International and National Yield Trials were B efficient. For example, 86% of BTYN 97/98 (Table 4.4.2) and all lines in IBYT 98/99 and IBON 98/99 were rated as moderately B efficient or B inefficient. As barley production is being promoted in areas where B deficiency is likely to be predominated. Results from this study suggest that yield loss due to B deficiency can be prevented by the use of B efficient genotypes. Boron efficiency should be included as selection criteria in breeding programmes.

6. INHERITANCE OF OF BORON EFFICIENCY IN BARLEY

6.1 Comparison of reciprocal crosses

Boron deficiency reduced number of spikelets spike^{-1} (Figure 6.1.1) grains spikelet^{-1} (Figure 6.1.2) and BGSI (Figure 6.1.3) but increased number of tillers plant^{-1} (Table 6.1.1 and Figure 6.1.4) of all parents and F_1 hybrids used in this study. The reductions in the first three characters of F_1 hybrids from both crosses were close to the more inefficient parents. For example, spikelets spike^{-1} of F_1 from BRB 9604 x BRB 9 crosses at B0 were the same as the more inefficient barley, BRB 9 (Figure 6.1.1a). In BRB 9 x BCMU 96-9 crosses (Figure 6.1.1b), spikelets spike^{-1} of F_1 at B0 were the same as both parents. At B10, spikelets spike^{-1} of BCMU 96-9 was higher than BRB 9 and those of F_1 were not differed from BCMU 96-9. This indicates the more sensitive of BCMU 96-9 to B deficiency and responses of F_1's were similar to BCMU 96-9. No different between reciprocal crosses were found.

Grain set of F_1 hybrids at B0 were within the range of parents but were closer to the more inefficient parents. No different between reciprocal crosses were found. (Figures 6.1.2 and 6.1.3). Grains spikelets^{-1} of BRB 9 x BCMU 96-9 at B10 were slightly lower than both parents. At B0, only BRB 9 parent set grain about 0.2 grains spike^{-1} and its BGSI was 12%. F_1 hybrids and BCMU 96-9 set no grain under B0 (Figures 6.1.2b and 6.1.3b).

B deficiency resulted in an increasing in tiller number of parents and F_1 in the present study (Table 6.1.1 and Figure 6.1.4). Compared to B10, tillers plant^{-1} of BRB 9604, BRB 9 and BCMU 96-9 at B0 were increased at 4, 12 and 26 tillers, respectively. F_1 hybrids tended to respond similar to the more responsive parents. In contrast to effect on tiller number, B deficiency had less effect on number of spikes (Table 6.1.1). No different between reciprocal crosses were found.

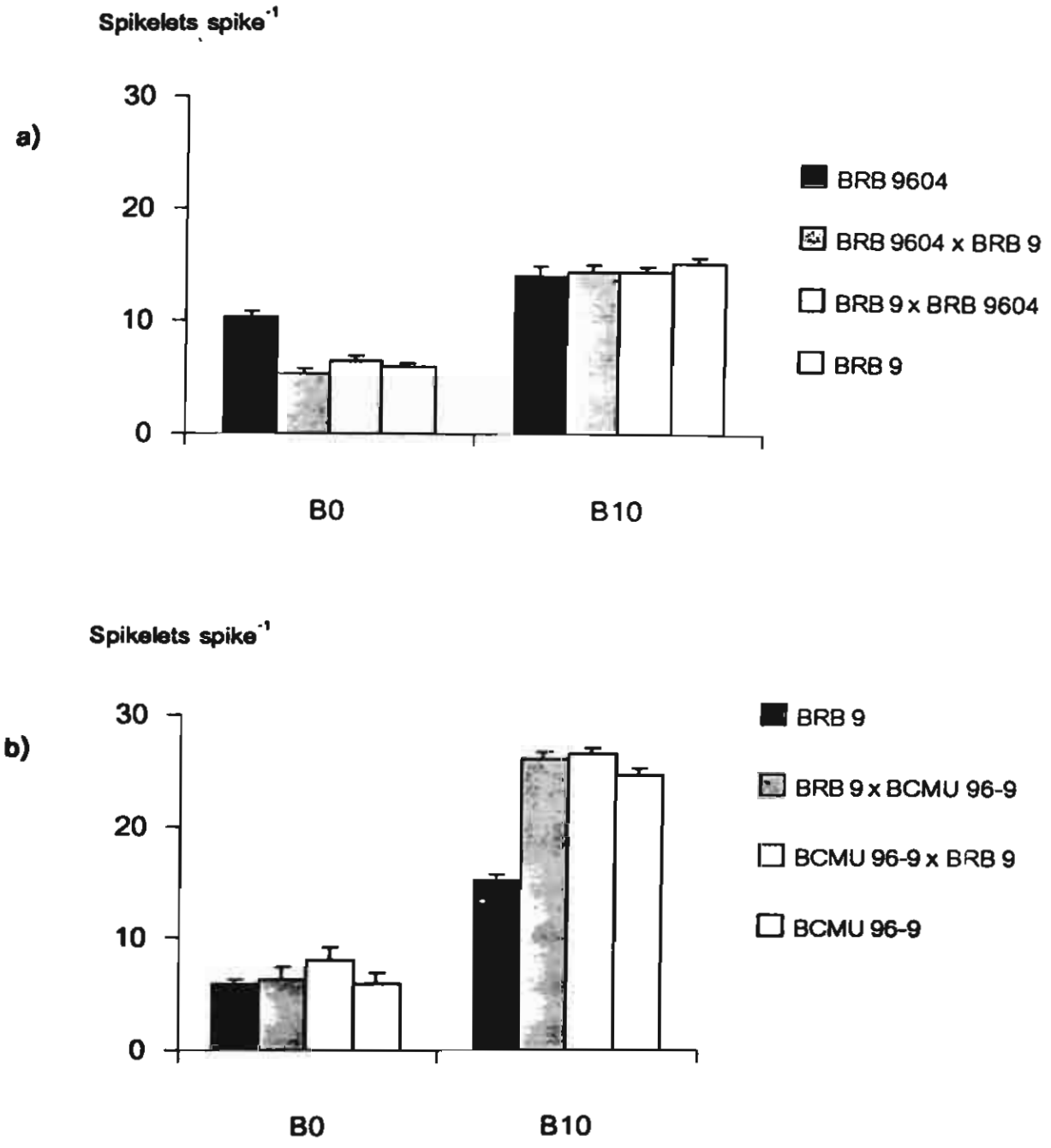


Figure 6.1.1 Number of spikelets spike^{-1} of parents and F_1 hybrids from crosses a) BRB 9604 x BRB 9 and b) BRB 9 x BCMU 96-9, grown in sand culture with 0 μMB (B0) and 10 μMB (B10). Data are means with standard error bars. Sand culture experiment 1, 1999/2000.

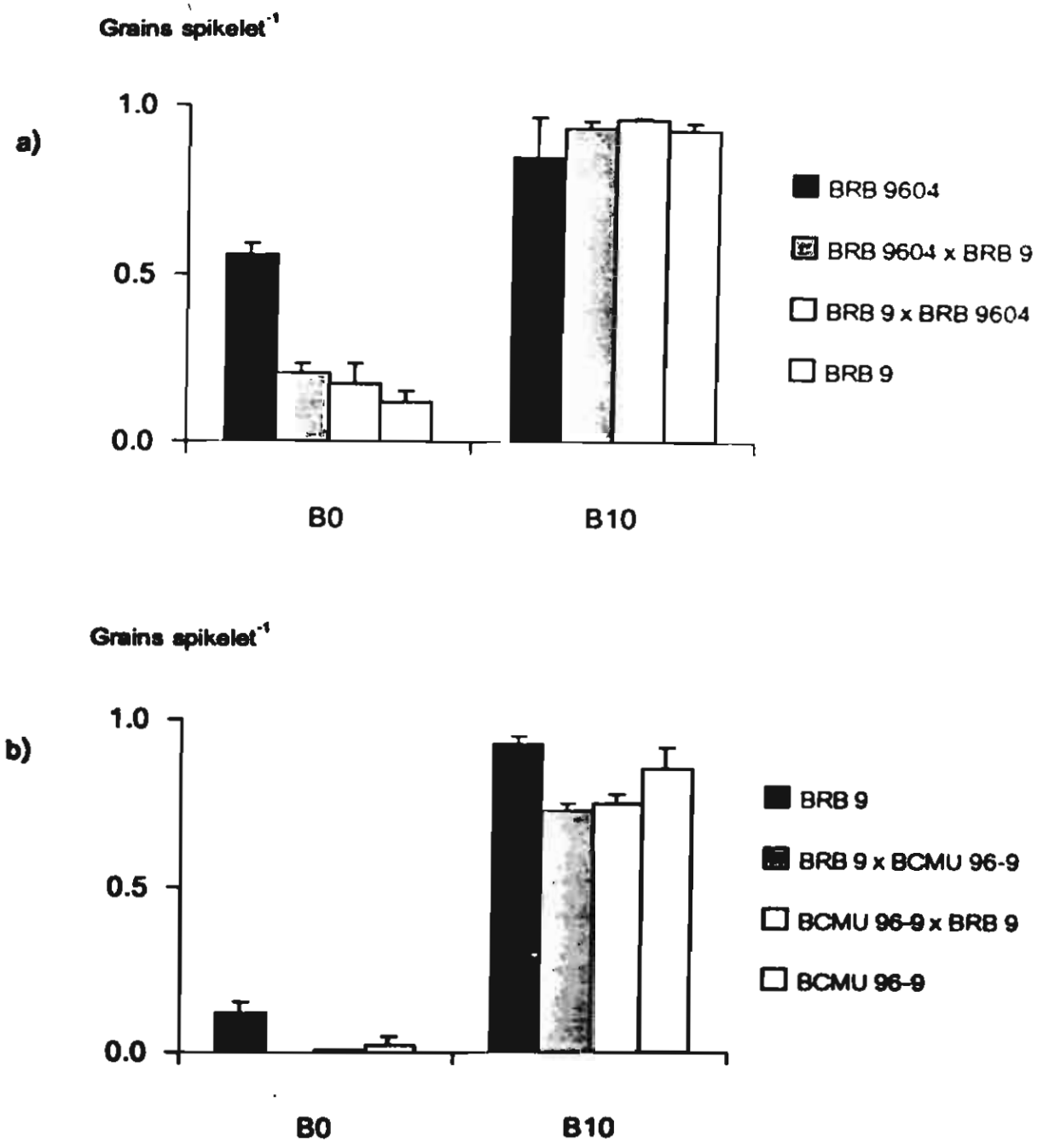


Figure 6.1.2 Number of grains spikelet^{-1} of parents and F_1 hybrids from crosses a) BRB 9604 x BRB 9 and b) BRB 9 x BCMU 96-9, grown in sand culture with 0 μMB (B0) and 10 μMB (B10). Data are means with standard error bars. Sand culture experiment 1, 1999/2000.

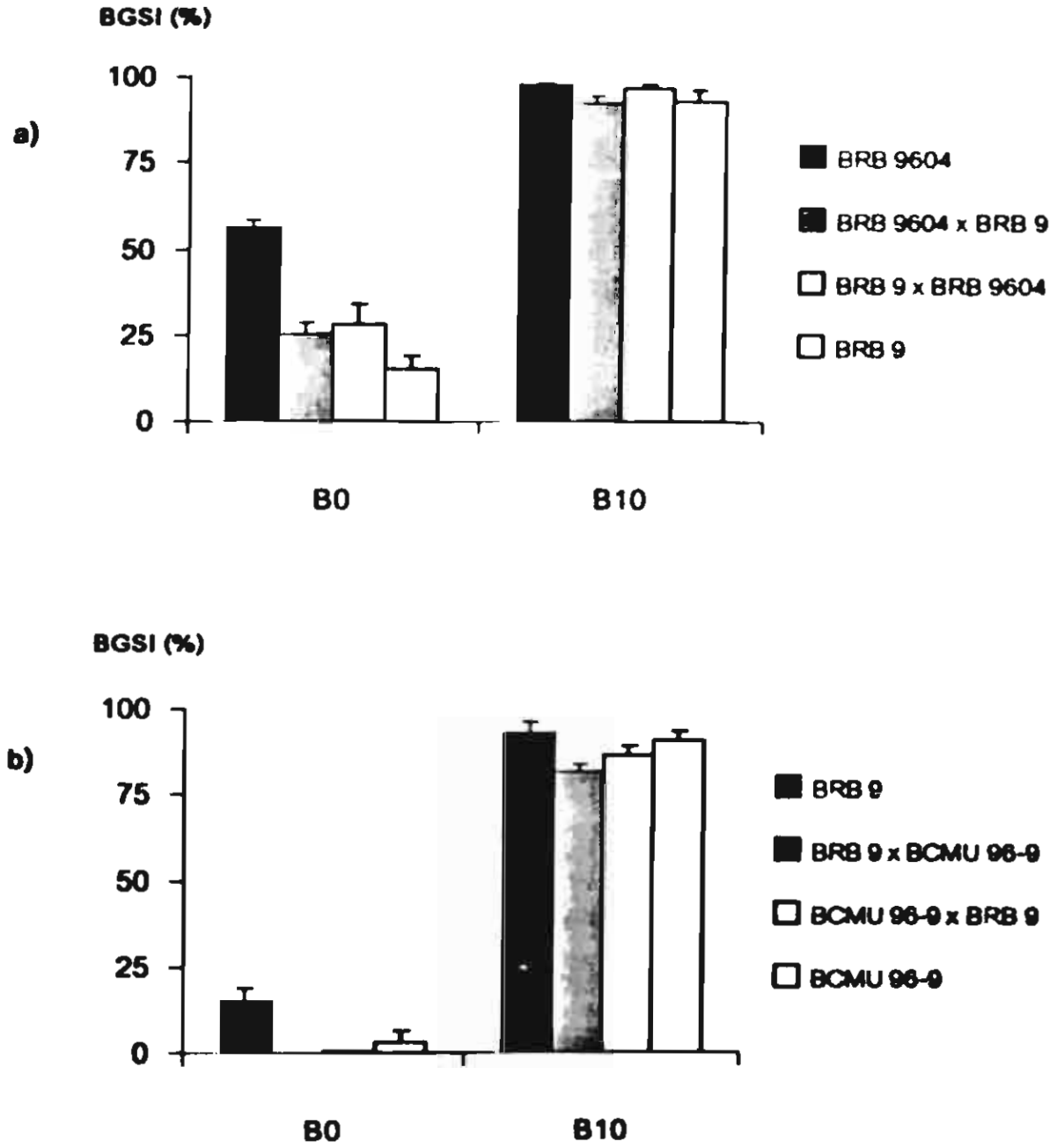


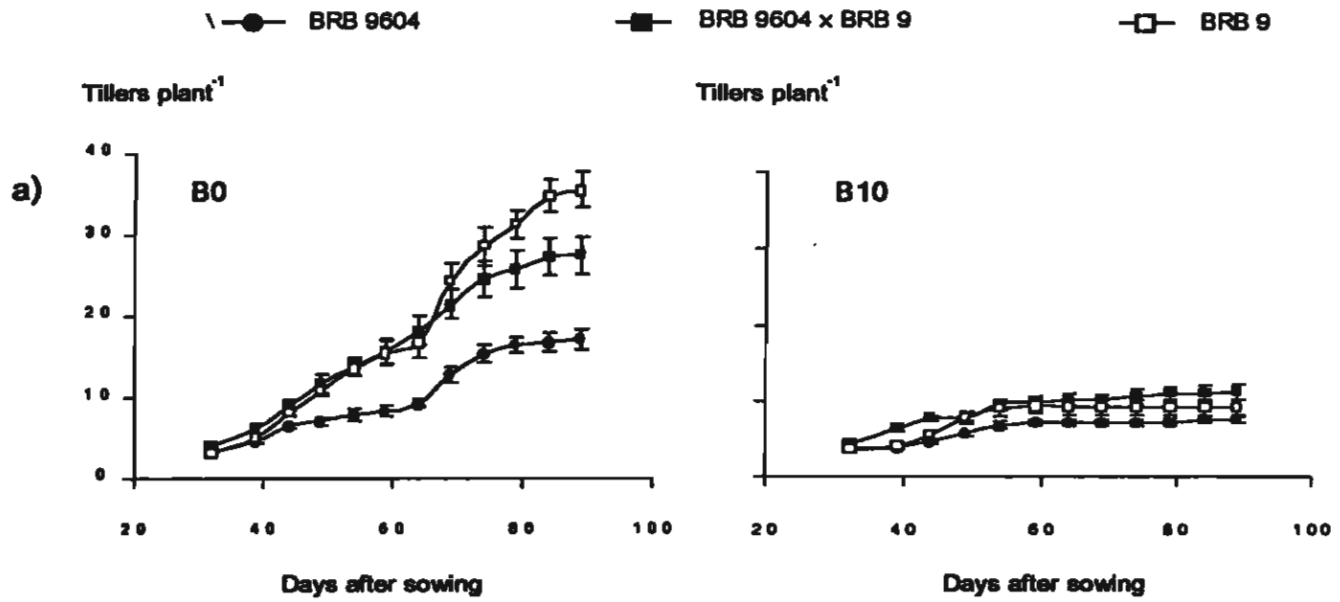
Figure 6.1.3 Barley Grain Set Index, BGSI (%) of parents and F_1 hybrids from crosses a) BRB 9604 x BRB 9 and b) BRB 9 x BCMU 96-9, grown in sand culture with 0 μMB (B0) and 10 μMB (B10). Data are means with standard error bars.

Table 6.1.1 Effect of B treatments (B0 and B10) on number of tillers plant^{-1} and spikes plant^{-1} at harvesting of parents and F_1 hybrids. Data are mean with standard error in parentheses. Sand culture experiment 1, 1999/2000.

Genotype	Tillers plant^{-1}		Spikes plant^{-1}	
	B0	B10	B0	B10
BRB 9604	17 (1)	13 (1)	7 (1)	9 (1)
BRB 9604 x BRB 9	26 (2)	12 (1)	10 (1)	11 (1)
BRB 9 x BRB 9604	29 (2)	11 (1)	10 (1)	9 (1)
BRB 9	36 (3)	14 (1)	12 (2)	11 (1)
BRB 9 x BCMU 96-9	31 (5)	8 (1)	5 (1)	7 (1)
BCMU 96-9 x BRB 9	33 (4)	9 (1)	4 (1)	6 (1)
BCMU 96-9	33 (2)	6 (1)	4 (1)	5 (1)

As reciprocal crosses were not different, reciprocal F_1 hybrids from each cross were pooled (Figure 6.1.4). It was shown that F_1 from BRB 9604 x BRB 9 were intermediate between parents at only close to maturity stage. At early stage, 20-50 days after sowing, tillers number of all barley genotypes at B0 and B10 were not differed significantly. At 50-70 days after sowing, tillers plants^{-1} of all parents and F_1 hybrids increased rapidly. This response may be a secondary effect of B deficiency induced by sterility. Differences between genotypes in spike number at B0 (Table 6.1.1) was not likely to be primarily induced by B deficiency, but it was likely caused by an ability of genotypes to develop each tiller into a spike at the later stage.

Parents and F_1 exhibited maximum number for spikelets spike^{-1}, grains spikelet^{-1} and BGSI when grown at B10. The absence of reciprocal differences in the F_1 hybrids for all measured characters demonstrate that response to B in barley is not cytoplasmically controlled.



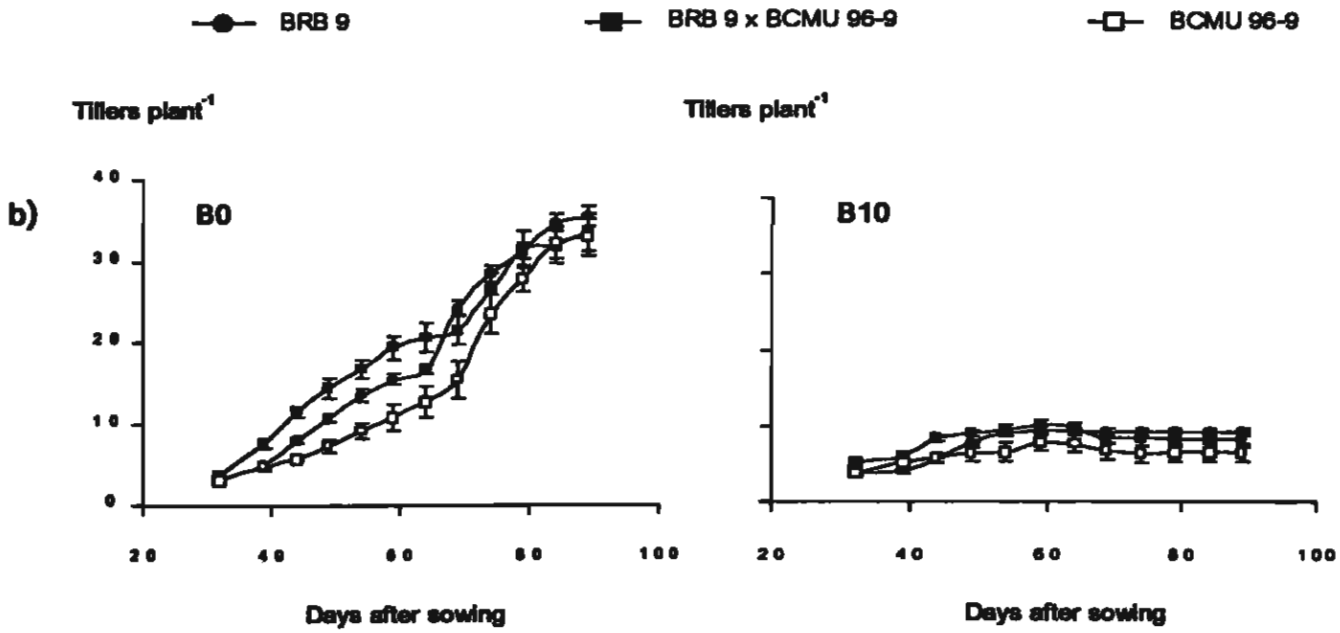


Figure 6.1.4 Number of tillers plant^{-1} of parents and F_1 hybrids from crosses a) BRB 9604 x BRB 9 and b) BRB 9 x BCMU 96-9, grown in sand culture with 0 μM B (B0) and 10 μM B (B10). Data are means with standard error bars. Sand culture experiment 1, 1999/2000.

6.2 Response of F_1 hybrids derived from five parents to B levels

From the previous sections, it was shown that BRB 9604 was the most B efficient barley genotype. Crosses between BRB 9604 and four genotypes varying levels of B response were evaluated in four levels of B in sand culture. Characters involving reproductive response were measured, namely, BGSI, number of spikelets spike^{-1} and grains spike^{-1}.

Responses of parents to B levels were consistent with previous sections. According to BGSI, which was used as an index for B efficiency (Jamjod and Rerkasem, 1999), parents were classified as; BRB 9604 as B efficient (E), BRB 9 as moderately inefficient (MI), BCMU 96-9 and Stirling as inefficeint (I), and SMGBL 94003 as very inefficient (VI) (Table 6.2.1).

Response of F_1 hybrids varied according to B treatment and parental combination. Significant different between F_1 and parental lines were shown in most crosses when grown at B 0 and B 0.1 μM (Table 6.2.1). At sufficient B, B 1.0 and B 10.0 μM, BGSI of all genotypes were between 72-98%. BGSI of cross between BRB 9604 (E) and BRB 9 (MI) was similar to the more efficient parent, BRB 9604 (E), at B 0 μM but was not different from both parents at B 0.1 μM. This suggests that B efficiency, in term of BGSI, in this cross was acted as a dominant trait only at the lowest B treatment. At B 0 μM BGSI of BRB 9604 (E) x BCMU 96-9 (I) and BRB 9604 (E) x Stirling (I) crosses were intermediate between the parents, indicated that additive gene action was operating in these crosses at this B level. In contrast, BGSI of BRB 9604 (E) x SMGBL 94003 (VI) cross was the same as that of the very inefficient parent, SMGBL 94003, indicating that inefficiency was dominant.

Number of grains spikelet^{-1} of F_1 hybrids of BRB 9604 (E) x BRB 9 (MI), BRB 9604 (E) x BCMU 96-9 (I) and BRB 9604 (E) x Stirling (I) at B 0 and B 0.1 μM were intermediate to the parental lines but close to B efficient parent, BRB 9604 (E) (Table 6.2.2). Therefore, B efficiency measured as grains spikelets^{-1} in these cross combinations was controlled by nearly complete dominant gene action. In contrast, grains spikelets^{-1} of BRB 9604 (E) x SMGBL 94003 (VI) was not differed from the VI parent which indicated the dominant of B inefficiency in this cross.

Table 6.2.1. Effect of B treatment on Barley Grain Set Index (BGSI, %) of parents and F_1 hybrids. Sand culture experiment 2, 1999/2000.

Parents/cross	B treatment (μM B)			
	0	0.1	1.0	10.0
BRB 9604	67.2 a	84.6 a	95.0 ab	93.8 a
BRB 9	34.0 c	74.0 a	99.2 a	98.3 a
BCMU 96-9	9.8 d	24.2 cd	89.2 abc	98.5 a
Stirling	13.4 d	26.3 cd	82.5 abc	95.8 a
SMGBL 94003	0.0 d	1.0 e	80.0 bc	72.9 b
BRB 9604 x BRB 9	54.2 ab	72.9 a	98.8 a	98.8 a
BRB 9604 x BCMU 96-9	44.8 bc	40.0 bc	98.3 a	96.7 a
BRB 9604 x Stirling	37.0 c	45.2 b	88.1 abc	97.3 a
BRB 9604 x SMGBL 94003	2.9 d	19.2 d	75.0 c	74.5 b

B x G was significant ($p<0.01$). Mean within a column with the same letter do not differ significantly at 5% level with LSD. To compare mean within a row LSD (0.05) = 16.9.

Table 6.2.2 Effect of B treatment on grains spikelet^{-1} parents and F_1 hybrids. Sand culture experiment 2, 1999/2000.

Parents/cross	B treatment (μM B)			
	0	0.1	1.0	10.0
BRB 9604	0.6 a	0.7 a	1.0 a	0.9 ab
BRB 9	0.3 bc	0.7 a	1.0 a	1.0 a
BCMU 96-9	0.3 bc	0.2 bc	0.9 a	0.9 ab
Stirling	0.1 cd	0.3 bc	1.0 a	1.0 a
SMGBL 94003	0.0 d	0.0 c	0.8 a	0.7 bc
BRB 9604 x BRB 9	0.5 ab	0.6 a	1.0 a	1.0 a
BRB 9604 x BCMU 96-9	0.4 ab	0.4 b	1.0 a	0.9 ab
BRB 9604 x Stirling	0.5 ab	0.7 a	1.0 a	1.0 ab
BRB 9604 x SMGBL 94003	0.0 d	0.2 bc	0.5 b	0.6 c

B x G was significant (p<0.01). Mean within a column with the same letter do not differ significantly at 5% level with LSD. To compare mean within a row LSD (0.05) = 0.2.

Parents used in this study exhibited different spikelets spike^{-1} when grown under sufficient B (Table 6.2.3). Therefore, response to B measured as percentage of B 10.0 μM was included. Response of parents based on spikelet number to B can be classified into only two groups. Spikelets spike^{-1} of BRB 9604 at B 0 and 0.1 μM were reduced to 71-85%, compared to the B 10.0 μM while those of the inefficient parents were between 29-59%.

Response of F_1 to B, compared to parental lines, ranging from intermediate to similar to the more inefficient parents (Table 6.2.3). Spikelets spike^{-1} of only BRB 9604 (E) x BRB 9 (MI) cross was intermediate between parents while those of the other crosses were similar to the more inefficient parents. This indicates that both additive and dominant gene actions were operating in this character with B inefficient acted as dominant trait.

The expression of B efficiency was controlled varying gene actions, depend on cross combination and severity of B deficiency. Response to low B of F_1 hybrids from the cross derived from B efficient (E) x moderately inefficient (MI) parents was intermediate between parents or close to the efficient parent. In contrast, F_1 form the B efficient (E) x inefficient (I) and B efficient (E) x very inefficient (VI) crosses tended to be close to or the same as the inefficient or very inefficient parents. Response to B deficiency is therefore expressed as a partially dominant trait, for these particular combinations. At B 1.0 and 10.0 μM responses of F_1 were not different from parents. Such a response is consistent with the hypothesis of Knight (1973) that for a quantitative trait the response of an F_1 hybrid relative to its parents, will vary according to the environment conditions.

The results suggested that level(s) of B deficiency should be carefully selected in screening segregating population derived from parents having contrast levels of B efficiency. For example, the B 0 μM treatment in this study was appropriate to screen progenies derived from BRB 9604 (E) x BRB 9 (MI), BRB 9604 (E) x BCMU 96-9 (I) and BRB 9604 (E) x Stirling (I) as this treatment provided the maximum discrimination between parents and its heterozygotes. The B 0 μM treatment could not distinguish the response of F_1 hybrid from the BRB 9604 (E) x SMGBL 94003 (VI) cross from the VI parent but significant variation between F_1 and the VI parents was found at the B 0.1 μM treatment. It is likely that B levels higher than the B 0.1 μM used the present study are required to separate progenies derived from crosses involving parents with lower levels of B efficiency than BRB 9604 (E).

Table 6.2.3. Effect of B treatment on spikelets spike^{-1} of parents and F_1 hybrids grown in sand culture. Relative number of spikelets spike^{-1} expressed as percentage of B10 are presented in brackets. Sand culture experiment 2, 1999/2000.

Parents/cross	B treatment (μM B)			
	0	0.1	1.0	10.0
BRB 9604	12.0	14.3	17.3	16.9
	(71)	*(85)*	*(102)*	*(100)*
BRB 9	7.9	8.9	18.3	17.5
	(45)	*(51)*	*(105)*	*(100)*
BCMU 96-9	9.4	11.8	27.9	28.8
	(33)	*(47)*	*(91)*	*(100)*
Stirling	8.8	9.8	21.0	23.2
	(38)	*(42)*	*(91)*	*(100)*
SMGBL 94003	7.7	9.2	27.0	26.8
	(29)	*(34)*	*(101)*	*(100)*
BRB 9604 x BRB 9	10.4	12.5	17.6	17.6
	(59)	*(71)*	*(101)*	*(100)*
BRB 9604 x BCMU 96-9	10.9	15.6	27.5	29.7
	(37)	*(53)*	*(91)*	*(100)*
BRB 9604 x Stirling	9.7	12.2	25.1	25.6
	(38)	*(48)*	*(98)*	*(100)*
BRB 9604 x SMGBL 94003	11.1	15.5	30.3	28.1
	(40)	*(55)*	*(108)*	*(100)*

B x G was significant (p<0.01). To compare mean within a row LSD (0.05) = 3.0.

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1. Jamjod S. and Rerkasem B. 1999. Genotypic variation in response of barley to boron deficiency. Plant Soil 215: 65-72.

2. Jamjod S., Boonsit P. and Rerkasem B. 2000. The genetic source for boron tolerance in barley. J. Agric. CMU. (In press)

APPENDIX

- **Published papers**

Plant and Soil 215: 65–72, 1999.

Genotypic variation in response of barley to boron deficiency

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Key words: barley, boron deficiency, *Hordeum vulgare*, *Triticum aestivum*, variation, wheat

Abstract

Responses of a range of barley (*Hordeum vulgare* L.) genotypes to boron (B) deficiency were studied in two experiments carried out in sand culture and in the field at Chiang Mai, Thailand. In experiment 1, two barley genotypes, Stirling (two-row) and BRB 2 (six-row) and one wheat (*Triticum aestivum* L.) genotype, SW 41, were evaluated in sand culture with three levels of applied B (0, 0.1 and 1.0 μM B) to the nutrient solution. It was found that B deficiency depressed flag leaf B concentration at booting, grain number and grain yield of all genotypes. In barley Stirling, B deficiency also depressed number of spikes plant^{-1}, spikelets spike^{-1} and straw yield. However, no significant difference between genotypes in flag leaf B concentration was found under low B treatments. Flag leaf B concentration below 4 mg kg^{-1} was associated with grain set reduction and could, therefore, be used as a general indicator for B status in barley. In experiment 2, nine barley and two wheat genotypes were evaluated in the field on a low B soil with three levels of B. Boron levels were varied by applying either 2 t of lime ha^{-1} (BL), no B (B0) or 10 kg Borax ha^{-1} (B+) to the soil prior to sowing. Genotypes differed in their B response for grain spike^{-1}, grain spikelet^{-1} and grain set index (GSI). The GSI of the B efficient wheat, Fang 60, exceeded 90% in all B treatments. The B inefficient wheat SW 41 and most of the barley genotypes set grain normally (GSI >80%) only at the B+. In B0 GSI of the barley genotypes ranged from 23% to 84%, and in BL from 19% to 65%. Three of the barley with severely depressed GSI in B0 and BL also had a decreased number of spikelets spike^{-1}. In experiment 3, 21 advanced barley lines from the Barley Thailand Yield Nursery 1997/98 (BTYN 1997/98) were screened for B response in sand culture with no added B. Grain Set Index of the Fang 60 and SW 41 checks were 98 and 65%, respectively, and GSI of barley lines ranged between 5 and 90%. One advanced line was identified as B efficient and two as moderately B efficient. The remaining lines ranked between moderately inefficient to inefficient. These experiments have established that there is a range of responses to B in barley genotypes. This variation in the B response was observed in vegetative as well as reproductive growth. Boron efficiency should be considered in breeding and selection of barley in low B soils.

Introduction

Boron (B) deficiency in wheat (*Triticum aestivum* L.) has been reported in many countries in Asia, i.e. China (Li et al., 1976), Nepal (Sthapit, 1988), India (Tandon and Naqvi, 1992) and Thailand (Rerkasem and Jamjod, 1989). The symptom of B deficiency has been described as male sterility, resulting in grain set failure. However, no apparent effect on any vegetative parts of the plants has been observed (Rerkasem et al., 1997). Large genotypic differences in B efficiency have been found within the modern, well adapted, wheat varieties (Rerkasem and Jamjod, 1997) and the use of efficient genotypes has been suggested for areas with low available soil B.

Barley (*Hordeum vulgare* L.) has been introduced to northern Thailand since the 1980s. Breeding programmes have been established in 15 research stations using genetic materials or advanced lines from CIMMYT and ICARDA. Barley experimental yields higher than 3 t ha^{-1} have been recorded in favourable

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conditions (Mann, 1991). However, severe sterility was observed when barley was grown in low B soil (0.1–0.2 mg B kg^{-1}), resulting in more than 50% yield reduction (Rerkasem and Jamjod, 1989). Moreover, little is known about B response of barley and its genotypic variation. The objectives of this study were to determine the effect of B deficiency on barley, to effectively screen barley genotypes for B efficiency and evaluate genotypic variability in response to B deficiency.

Materials and methods

Experiment 1: Sand culture experiment

Two barley varieties differing in spike type and one bread wheat genotype were chosen. These were Stirling; a two-row barley, BRB 2; a six-row type barley and SW 41, a moderately B inefficient wheat (Rerkasem and Loneragan, 1994). Twenty seeds of each genotype were sown in freely drained, earthernware pots (0.3 m diameter and 0.3 m deep) containing washed river quartz sand. Pots were supplied twice daily with complete nutrient solution with three levels of B (0, 0.1 and 1.0 μM B). The nutrient solution was adapted from Broughton and Dilworth (1971), consisted of (μM): $CaCl_2$, 1000; $MgSO_4$, 250; KH_2PO_4, 500; FeEDTA, 10; K_2SO_4, 250; $MnSO_4$, 2; ZnSO4, 0.5; CuSO4, 0.2; $CoSO_4$, 0.1; Na_2MoO_2, 0.1 and KNO_3, 5000. Genotypes and B levels were arranged factorially with six replications. Seven days after germination, seedlings were thinned to 10 plants per pot. At ear emergence, 20 randomly selected flag leaves were sampled from each pot and B was analyzed by dry ashing azomethine-H determination (Lohse, 1982). At maturity, spikes in each pot were counted to estimate the number of spikes per plant. Two spikes from each plant, or 20 spikes per pot, were randomly collected to determine spikelets $spike^{-1}$, grains $spikelet^{-1}$ and Grain Set Index (GSI). The GSI for SW 41 wheat was measured as percentage of the 20 basal florets from 10 spikelets with grains, in order to distinguish effects on grain set from those on grain filling (Rerkasem and Loneragan, 1994). To standardize grain set performance between the three types of spike, the term 'spikelet' used in this study was defined as the median spikelet for Stirling (two-row barley) and the median spikelet plus two lateral spikelets for BRB 2 (six-row barley). Therefore, GSI for barley was measured as a percentage of the 10 median spikelets from 10 spikelets with grains for the two-row type and of the 20 lateral spikelets from 10 spikelets with grains for the six-row type. Grain and straw dry weight were determined for each pot. Seed size was determined as the weight of 100 seeds (100 SW).

Experiment 2: Field experiment

Nine barley lines, a B-efficient (Fang 60, Jamjod et al., 1992) and an inefficient (SW 41) wheat were grown in the field with three B treatments in four replications. The three B treatments were imposed by applying either lime (2 t ha^{-1}, designated as BL, to accentuate B deficiency, Rerkasem and Jamjod (1989)), nil (B0) or 10 kg Borax ha^{-1} (B+) to the soil before sowing. Each genotype was sown at 3 g m^{-1} in three-2 m rows, 0.25 m between rows, in each B treatment and replicate. At boot stage (Zadok 45, Zadok et al., 1974), 20 spikes from the main stem were randomly selected from the three-row plot and bagged. At maturity, selected spikes were harvested and spikelets $spike^{-1}$, grains $spikelet^{-1}$ and GSI determined.

Experiment 3: Sand culture screening

The Barley Thailand Yield Nursery (BTYN 1997/98) which had 21 advanced lines was screened for response to B. The screening was conducted in trays (0.45m × 0.70m × 0.35m) containing sand and watered with nutrient solution without added B as described in experiment 1. Five seeds of each line were sown in rows with 60 mm between seeds and 60 mm between rows. The wheat checks, described above, were also included. The genotypes were arranged in a randomized complete block design with three replications. At early boot stage, the first two spikes of each plant were bagged. At maturity, the bagged spikes of each line were harvested, GSI determined and compared to the wheat checks.

Statistical analysis

Data were analyzed statistically by analysis of variance. Significantly different means were separated at the 0.05 probability level (Steel and Torrie, 1960). Correlation coefficients between characteristics were computed from the mean of the six replications.

Results

Sand culture experiment

Grain yield was affected by boron and genotype (Table 1). Boron x genotype interaction effect was not significant; therefore, grain yield of the three genotypes responded similarly to B levels. At the lowest B treatment, grain yields of all genotypes were significantly reduced compared to the 1.0 μM B treatment. Straw yields of BRB 2 and SW 41 were not affected by B treatments, whereas that of Stirling increased with B. Grain yield of Stirling was depressed by the reduction in number of spikes plant^{-1}, spikelets spike^{-1}, grains spikelet^{-1} and GSI (Figures 1 and 2). In contrast, grain yield of BRB 2 and SW 41 were reduced mainly due to a lower number of grains spikelet^{-1} and GSI. Boron deficiency significantly increased seed size or 100 seed weight of SW 41 wheat (Figure 1), indicating a compensation effect for seed set reduction. This effect was not observed in either Stirling or BRB 2 barley.

Highly significant correlations of GSI with grains spike^{-1}, grains spikelet^{-1} and yield were demonstrated in the low B treatments (Table 2). With 1.0 μM B, GSI of most genotypes were >80% and did not correlate with grains spike^{-1} and grains spikelet^{-1}. At 0.1 and 1.0 μM B, slightly negative correlations between seed size with either GSI or yield were shown. Neither GSI nor grain yield was significant correlated with spikelet spike^{-1}. Grain yield was positively correlated ($p < 0.01$) with grains spike^{-1}, grains spikelets^{-1} and GSI in all B treatments.

Boron in the flag leaf of barley and wheat increased with external B supply (Figure 3). No significant difference in flag leaf B between genotypes was observed at B0 and 0.1 μM. All genotypes had flag leaf B approximately 2–3 mg B kg^{-1} in B0 and 3–4 mg B kg^{-1} in B0.1 μM. At the highest B level, the SW 41 wheat had 4–5 mg kg^{-1}, whereas flag leaf B of both barley were increased to 7–8 mg kg^{-1}.

Field experiment

Boron had no effect on the number of spikelets of all six-row barley genotypes, as well as wheat checks, Fang 60 and SW 41 (Table 3). However, the number of spikelets spike^{-1} of three two-row barleys, namely, Stirling, SMGBLS 91002 and SMGBLS 94003, showed clear positive responses to increasing B.

Table 1. Effects of B treatments on (a) grain yield and (b) straw yield of barley and wheat genotypes. Experiment 1

	Genotype	B treatment[b] (μM)		
		0	0.1	1.0
(a)	Grain yield (g pot^{-1})			
	Stirling	2.6 a	6.2 a	19.0 b
	BRB 2	7.3 a	9.5 a	25.6 b
	SW 41	24.8 a	29.2 a	36.9 b
	F-test[a] B***, G***, B x G^{ns}			
(b)	Straw yield (g pot^{-1})			
	Stirling	88.9 a	96.3 ab	115.9 b
	BRB 2	79.7 a	101.2 a	82.2 a
	SW 41	78.5 a	70.9 a	64.5 a
	F-test B^{ns}, G***, B x G**			

[a] ** and *** Significant at 0.01 and 0.001 probability levels, respectively; ^{ns} not significant.
[b] Mean within a row with the same letter do not differ significantly at 5% level with Duncan's Multiple Range Test.

Very significant interaction between B treatments and genotypes was observed on grains spike^{-1} (Table 4) and grains spikelet^{-1} (Table 5). Grains spike^{-1} and grains spikelet^{-1} of SW 41, the B inefficient check and most barley genotypes were lowest in the BL treatment and increased with increasing B, whereas those of Fang 60 remained constant.

When all genotypes were compared using GSI (Table 6), they can be classified into four different groups. Fang 60 was the most efficient genotype and had more than 90% GSI in all B treatments. CMBL 92029, BRB 9, SMGBLS 91002, SMGBLS 94003, BCMU 96-5 and BRB 2 had low GSI similar to SW 41 and were classed as inefficient to B. The GSI of BCMU 96-9 and BCMU 96-1 at BL and B0 were intermediate between those of SW 41 and Fang 60, and were classified as moderately efficient. Stirling was the most inefficient genotype, its GSI was 19, 23 and 79% in BL, B0 and B+, respectively.

Sand culture screening

Without B added to the nutrient solution, GSI of Fang 60 and SW 41 were 98.3 and 65.1%, respectively (Table 7). When compared with the wheat checks, only one barley line, BRB 9604, set grain better than SW 41 and comparable to Fang 60 (Table 7). Grain Set Index of of the remaining lines were either similar to or less than SW 41, with the exception of BRB 9624 and BRB 9. Grain Set Index of these two lines were intermediate between the two wheat checks.

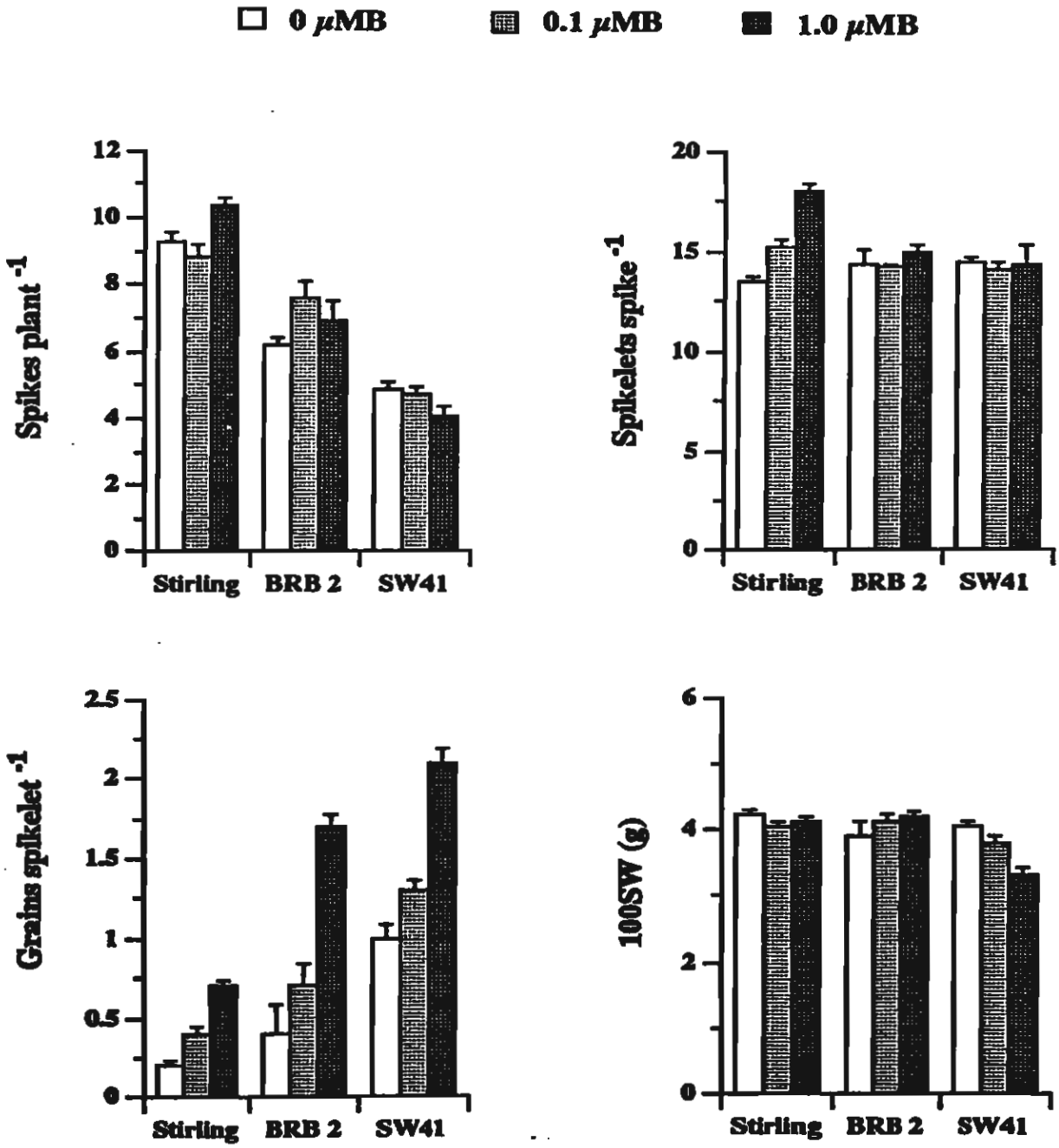

Figure 1. Effects of B treatment on yield components of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture. Experiment 1.

Discussion

Grain yield of the two barley, BRB 2 and Stirling, as well as SW 41 wheat was depressed by B deficiency through grain set, i.e. grains spikelet^{-1} and GSI. Boron deficiency has been reported to depress grain yield while increasing tillering and straw yield in one Japanese barley variety (Ambak and Tadano, 1991). This effect was not observed in the present study. Moreover, in Stirling B, deficiency also depressed spikes plant^{-1}, spikelets spike^{-1} and straw yield. A genotypic variation in vegetative responses to B is suggested by these results. Furthermore, the depression of spikelet number by B deficiency was

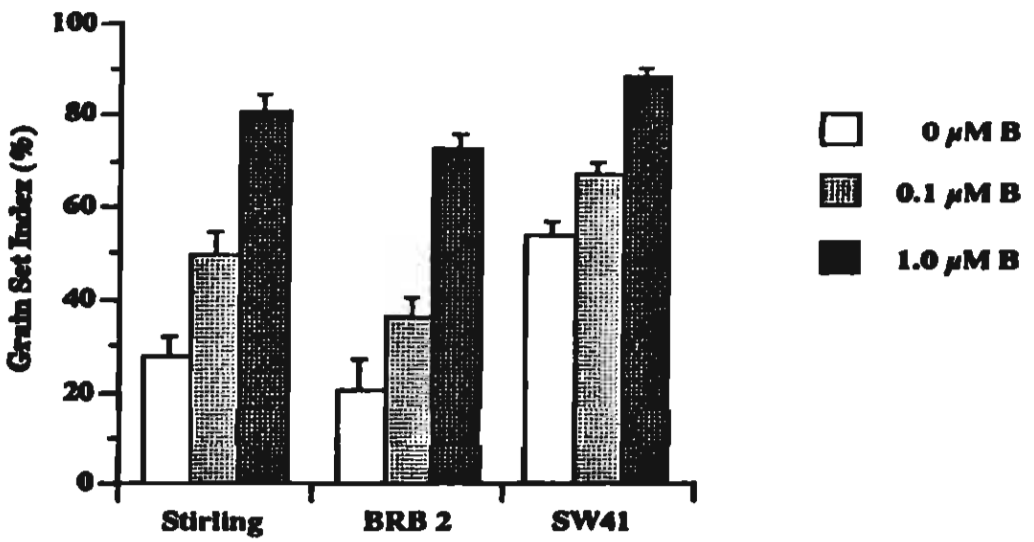

Figure 2. Effects of B treatment on Grain Set Index (%) of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture. Experiment 1.

Table 2. Correlation coefficient (*r*) between Grain Set Index (GSI) or grain yield (italics) and yield components. Experiment 1

B treatment		Spikelets spike^{-1}	Grains spike^{-1}	Grains spikelet^{-1}	100SW	GSI
0 μM	GSI	0.11	0.89**	0.89**	0.38	–
	Grain yield	*0.27*	*0.88***	*0.87***	*0.09*	*0.81***
0.1 μM	GSI	0.01	0.72**	0.70**	−0.49*	–
	Grain yield	*−0.23*	*0.80***	*0.89***	*−0.48**	*0.75***
1.0 μM	GSI	0.13	0.37	0.29	−0.64**	–
	Grain yield	*−0.08*	*0.79***	*0.68***	*−0.49**	*0.65***

* and ** Significant at the 0.05 and 0.01 probability levels, respectively.

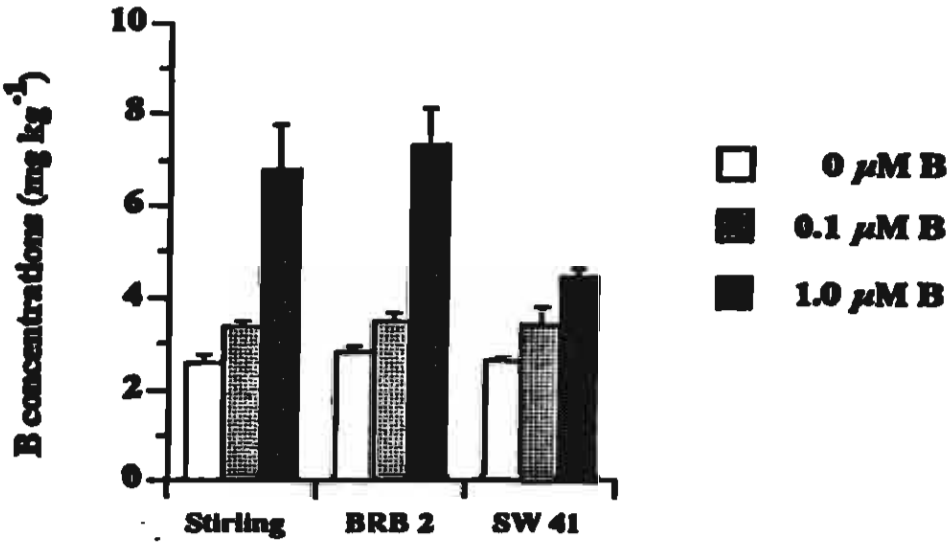

Figure 3. Effects of B treatments on B concentration in flag leaf of two barley genotypes, Stirling and BRB 2, and SW 41 wheat grown in sand culture. Experiment 1.

Table 3. Effect of B treatments on spikelet spike^{-1} of barley and wheat genotypes. Experiment 2

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	22.2 a	23.8 a	22.9 a
BRB 9	14.6 a	14.0 a	13.3 a
CMBL 92029	17.9 a	19.7 a	20.5 a
SMGBLS 91002	21.4 a	23.3 ab	25.0 b
SMGBLS 94003	21.5 a	24.4 b	23.8 ab
Stirling	15.6 a	18.5 b	19.4 b
Six-row barley			
BCMU 96-1	18.9 a	18.5 a	16.8 a
BCMU 96-5	15.7 a	18.5 a	16.9 a
BRB 2	17.0 a	18.4 a	16.5 a
Wheat			
Fang 60	13.2 a	13.9 a	12.8 a
SW 41	14.6 a	15.4 a	15.6 a
F-test[a] B^{ns}, G**, BxG*			

[a] * and ** Significant at 0.05 and 0.01 probability levels, respectively; ns not significant.
[b] Mean within a row with the same letter do not differ significantly at 5% level with Duncan's Multiple Range Test.

Table 4. Effect of B treatments on grains spike^{-1} of barley and wheat genotypes. Experiment 2

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	12.1 a	18.3 a	19.1 a
BRB 9	6.6 a	7.9 a	11.7 a
CMBL 92029	8.1 a	6.0 a	12.2 a
SMGBLS 91002	3.6 a	10.1 ab	18.5 b
SMGBLS 94003	5.8 a	10.7 ab	16.4 b
Stirling	2.6 a	3.8 a	11.3 b
Six-row barley			
BCMU 96-1	30.8 a	38.6 ab	41.0 b
BCMU 96-5	18.0 a	30.0 b	40.3 c
BRB 2	23.5 a	34.0 b	36.6 b
Wheat			
Fang 60	36.3 a	39.0 a	33.0 a
SW 41	14.8 a	19.0 a	34.2 b
F-test[a] B**, G**, BxG**			

[a] ** Significant at 0.01 probability level.
[b] Mean within a row with the same letter do not differ significantly at 5% level with Duncan's Multiple Range Test.

also observed in Stirling and two other two-row barley genotypes when tested in the field (Table 3). As previously reported (Rerkasem et al., 1997; Rerkasem and Jamjod, 1989), this effect of B on this secondary reproductive organ was not observed in wheat and six-row barley used in this study.

Flag leaf B concentration at boot stage was significantly increased with increasing B levels. However, no genotypic differential response was observed. For example, SW 41, BRB 2 and Stirling had similar flag leaf B concentration at low B treatments (>2–4 mg kg^{-1}) and increased to 4–5 mg kg^{-1} for SW 41 wheat, and 7–8 mg kg^{-1} for the two barleys, at the B 1.0 μM treatment. In wheat grown in sand culture, Rerkasem and Loneragan (1994) reported that flag leaf B concentration below 3 mg kg^{-1} at boot stage was involved with depressed wheat grain set. In barley, Simojoki (1972) found that leaf B concentration of barley genotypes grown in low B soil were between 4 and 5 mg kg^{-1} and increased to 7–9 mg kg^{-1} when 600 g B ha^{-1} was applied. Flag leaf B concentration can be used as a general indicator for B status of barley and concentrations <4 mg B kg^{-1} appear to predict a decline in grain set from B deficiency.

Sterility can be measured in a number of ways, such as grains spike^{-1}, grains spikelet^{-1} and GSI, as these characters responded positively to external B levels and closely correlated to grain yield in wheat (Rerkasem and Loneragan, 1994). In studies involving response of individual genotypes to B levels, grains spike^{-1} and grains spikelet $^{-1}$can be used. However, when several genotypes are compared for response to B, for example, within and between spike types of barley and wheat, the use of grains spike^{-1} or grains spikelet^{-1}may lead to misclassification because genotypes differed in spike type, spike size i.e. spikelets spike^{-1} and even floret spikelet^{-1} in the case of wheat (Tables 4 and 5). The use of GSI to compare the effect of B on grain set (Anantawiroon et al., 1997) successfully avoids these problems. Highly significant correlation of GSI with grains spike^{-1}, grains spikelet^{-1} and yield were demonstrated in the low B treatments (Table 2). At high B level, GSI of most genotypes were >80% and did not correlated with grains spike^{-1} and grains spikelet^{-1}, which indicates the de-

pendence of GSI on B levels. The term GSI, generally, refers to the fertility percentage of ten central spikelets of barley or wheat. Since the structure of barley spikes is different from that of wheat, and two-row barley is also different from six-row barley, the term 'Barley Grain Set Index, BGSI', defined as percentage of the ten central spikelets (ten median spikelets for two-row barley and 20 lateral spikelets for six-row barley) on a spike with grains, should be used in order to distinguish it from the GSI used in wheat.

Considerable genotypic variation in B efficiency was observed in advanced lines of barley screened in soil and sand culture. Of the 30 barley genotypes tested in low B, BGSI of five lines were higher than the moderately B inefficient wheat, SW 41 (Tables 6 and 7). Most lines were screened and selected in Northern Thailand, where B deficiency has been reported in wheat and some barley lines (Rerkasem and Jamjod, 1989). The majority of segregating populations and advanced lines used in barley breeding programmes in Thailand were obtained through CIMMYT. Substantial numbers of B efficient wheat lines have been identified from CIMMYT materials (Jamjod et al., 1992; Subedi et al., 1997) and the same may be true for barley. It is likely that B efficiency in barley is already available in these germplasms. However, the present results have screened only a small selection of the total variation for all barley. Further screening of germplasms from other sources is required to define the full range of B response for barley.

Table 5. Effect of B treatments on grains spikelet^{-1} of barley and wheat genotypes. Experiment 2

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	0.5 a	0.8 a	0.8 a
BRB 9	0.5 a	0.6 a	0.9 a
CMBL 92029	0.4 a	0.3 a	0.6 a
SMGBLS 91002	0.2 a	0.4 ab	0.7 b
SMGBLS 94003	0.3 a	0.4 a	0.7 a
Stirling	0.2 a	0.2 a	0.6 b
Six-row barley			
BCMU 96-1	1.6 a	2.1 ab	2.4 b
BCMU 96-5	1.1 a	1.6 b	2.4 c
BRB 2	1.4 a	1.8 ab	2.2 b
Wheat			
Fang 60	2.7 a	2.8 a	2.6 a
SW 41	1.0 a	1.2 ab	2.2 b
F-test[a] B**, G**, BxG**			

[a] ** Significant at 0.01 probability level.
[b] Mean within a row with the same letter do not differ significantly at 5% level with Duncan's Multiple Range Test.

Table 6. Effect of B treatments on Grain Set Index (%) of barley and wheat genotypes. Experiment 2

Genotype	B treatments[b]		
	BL	B0	B+
Two-row barley			
BCMU 96-9	65.6 e	84.2 de	91.2 ab
BRB 9	48.1 cde	61.5 bc	90.5 ab
CMBL 92029	42.3 bcd	33.0 a	67.3 a
SMGBLS 91002	27.0 ab	61.5 bc	92.8 b
SMGBLS 94003	36.4 abc	55.8 bc	85.4 ab
Stirling	19.0 a	23.1 a	79.1 ab
Six-row barley			
BCMU 96-1	60.1 de	74.7 cd	89.1 ab
BCMU 96-5	43.9 bcd	63.8 bcd	86.6 ab
BRB 2	40.5 bcd	71.9 bcd	83.4 ab
Wheat			
Fang 60	94.4 f	97.0 e	96.6 b
SW 41	42.7 bcd	52.5 b	93.0 b
F-test[a] B**, G**, BxG**			

[a] ** Significant at 0.01 probability level.
[b] Mean within a column with the same letter do not differ significantly at 5% level with Duncan's Multiple Range Test.

These results have shown that genotypic variation in B response exists in barley. In addition to the effect on male sterility, as in wheat, the B response in barley was also observed in number of spikes plant^{-1}, spikelets spike^{-1} and straw yield. Consideration of B efficiency should be useful in barley breeding and selection programmes for low B soils.

Acknowledgements

This research was supported by a grant from the Thailand Research Fund. The authors wish to thank Dr Richard Bell for his valuable comments and suggestions.

Table 7. Response of advanced lines from Barley Thailand Yield Nurseries 1997/98 tested in sand culture with B0. Experiment 3

Line	Origin[a]	GSI (%)	% of checks	
			Fang 60	SW 41
Two-row barley				
BRB 9604	BRB	90.0	91	138 *
BRB 9624	BRB	85.3	87	131
BRB 9	BRB	79.9	81	123
BRB 9609	BRB	75.2	76 *	115
BRB 10	BRB	74.5	76 *	114
BRB 11	BRB	72.5	74 *	111
LARTC-BL9101 (14)	LMP	64.1	65 **	98
BRB 9621	BRB	61.5	62 **	94
LARTC-BL9119 (11)	LMP	60.7	62 **	93
LARTC-BL9408	LMP	47.9	49 ***	73
SMGBL 94026	SMG	42.3	43 ***	66 *
LARTC-BL9410	LMP	40.4	41 ***	62 *
SMGBL 94003	SMG	4.8	5 ***	8 ***
Six-row barley				
FNBL 8309-34-SMG-1-1	SMG	55.2	56 ***	85
FNBL 8306-BC-SMG-1-1	SMG	46.5	47 ***	71
FNBL #140	SMG	45.9	47 ***	70
FNBL 8404-4-SMG-1-1-1	SMG	38.9	40 ***	60 **
FNBL 8403-6-SMG-1-2-1	SMG	37.0	38 ***	57 **
FNBL 8403-17-SMG-1-1-1	SMG	34.5	35 ***	53 **
SMG 1	SMG	31.9	32 ***	49 **
BRB 2	BRB	24.7	25 ***	38 ***
Wheat (checks)				
Fang 60		98.3	100	151 **
SW 41		65.1	66 **	100

[a] LMP = Lampang Agricultural Research Training Center.
BRB = Boon Rawd Brewery Co. Ltd.
SMG = Samoeng Upland Rice and Temperate Cereals Experiment Station.
*, ** and *** Significantly different from check cultivars at $p<$ 0.05, 0.01 and 0.001, respectively.

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วารสารเกษตร (In press)

แหล่งพันธุกรรมของความทนทานต่อการขาดธาตุโบรอนในข้าวบาร์เลย์

The Genetic Source for Boron Tolerance in Barley

สันสนีย์ จำจด ปณิตา บุญสิทธิ์ และ เบญจวรรณ ฤกษ์เกษม [1]

Sansanee Jamjod, Panita Boonsit and Benjavan Rerkasem [1]

Abstract : Responses of barley genotypes to boron (B) were studied in two growing season, 1997/98 and 1998/99. A preliminary screening was conducted in the first season with advanced lines of barley from the Barley Thailand Yield Nurseries 97/98. The barley lines were tested in sand culture containing washed river quartz sand, watered with complete nutrient solution without added B. Boron efficient (Fang 60) and moderately inefficient (SW 41) wheat genotypes were included as checks. Barley genotypes with different levels of B tolerance were selected for further screening in the next season.

In 1998/99, the selected barley lines and 4 wheat checks (ranging from B inefficient to efficient) were evaluated on a low B soil in a split plot design. The B levels were in main plots in four replications and genotypes were in subplots. Boron levels included nil (B0), 1 kg borax ha^{-1} (B1), 10 kg borax ha^{-1} (B2) and 2000 kg lime ha^{-1}, to accentuate B deficiency (BL). Barley genotypes were found to vary in their response to B in terms of number of grains ear^{-1}, grains $spikelet^{-1}$, grain set index (GSI) and grain yield.

The range of responses found was comparable to that expressed in the wheat checks. In the low B treatments, grain set was severely depressed in many of the barley genotypes but not in BRB 9604 and BRB 9642. These two genotypes of barley appear to

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be as tolerant to B deficiency as Fang 60, the most B efficient wheat. Such barley genotypes may be expected to avoid B deficiency-induced grain set problem in low B soils in the Northern and Northeastern Thailand. BRB 9604 and BRB 9642 might also be used as sources of B efficiency in breeding programmes.

บทคัดย่อ: การทดลองครั้งนี้ได้ศึกษาการตอบสนองของสายพันธุ์ข้าวบาร์เลย์ต่อการขาดธาตุโบรอน โดยศึกษาในฤดูปลูก 2540/41 และ 2541/42 ในฤดูปลูกแรกเป็นการทดสอบในขั้นต้นโดยใช้สายพันธุ์ข้าวบาร์เลย์จากชุดเปรียบเทียบผลผลิต BTYN 97/98 ปลูกในสภาพขาดโบรอนใน sand culture เปรียบเทียบกับข้าวสาลีพันธุ์มาตรฐานที่ทราบระดับความทนทานต่อการขาดโบรอน เพื่อคัดเลือกสายพันธุ์ข้าวบาร์เลย์ที่มีระดับความทนต่อการขาดโบรอนแตกต่างกันปลูกทดสอบในฤดูปลูกถัดไป

ฤดูปลูกที่สองเป็นการเปรียบเทียบสายพันธุ์ข้าวบาร์เลย์ที่คัดเลือกและข้าวสาลีพันธุ์มาตรฐานในแปลงทดลองวางแผนการทดลองแบบ split plot มี 4 ซ้ำให้ระดับโบรอน 4 ระดับเป็น main plot และพันธุ์เป็น sub plot พบความแตกต่างระหว่างพันธุ์ข้าวบาร์เลย์ในการตอบสนองต่อระดับธาตุโบรอนในลักษณะจำนวนเมล็ดต่อรวง จำนวนเมล็ดต่อช่อดอก ดัชนีการติดเมล็ดและผลผลิต ความแปรปรวนทางพันธุกรรมพบว่าอยู่ในระดับที่ใกล้เคียงกับที่พบในข้าวสาลี ในขณะที่ข้าวบาร์เลย์สายพันธุ์อื่นๆ มีปัญหาการขาดธาตุโบรอน สายพันธุ์ BRB 9604 และ BRB 9642 ทนทานต่อการขาดโบรอนได้ดีพอๆ กับข้าวสาลี Fang60 ซึ่งมีความทนทานสูงสุดต่อการขาดโบรอน สายพันธุ์เหล่านี้สามารถแนะนำปลูกหรือใช้เป็นพ่อแม่พันธุ์ในโครงการปรับปรุงพันธุ์เพื่อส่งเสริมปลูกในท้องที่ที่ดินมีปัญหาขาดธาตุโบรอน

Index words : ข้าวบาร์เลย์ ธาตุโบรอน ความแปรปรวนทางพันธุกรรม ข้าวสาลี

Barley, boron, genetic variation, wheat

คำนำ

พื้นที่เป้าหมายสำหรับการส่งเสริมการปลูกธัญพืชเมืองหนาวในประเทศไทย โดยเฉพาะภาคเหนือตอนบนและภาคตะวันออกเฉียงเหนือนั้น พบดินที่มีธาตุโบรอนต่ำกระจายอยู่ทั่วไป (เบญจวรรณ, 2538; เพิ่มพูน, 2538; Rerkasem et al., 1989) อาการขาดโบรอนในข้าวสาลีและข้าวบาร์เลย์จะแสดงออกในลักษณะการที่รวงเป็นหมัน สามารถสังเกตได้ในระยะหลังดอกผสมเกสร โดยจะพบว่ารวงจะมีลักษณะโปร่งใส เกสรตัวผู้ฝ่อ และหลังจากนั้นรวงจะลีบไม่ติดเมล็ดเนื่องจากไม่มีการผสมเกสร ซึ่งเป็นผลมาจากพัฒนาการของละอองเรณูล้มเหลว (เบญจวรรณและศันสนีย์, 2532; Rerkasem et al., 1997)

การแก้ปัญหาการสูญเสียผลผลิตเนื่องจากขาดโบรอนในธัญพืชที่พบว่าได้ผลคือการใส่โบรอนลงไปในดินและการใช้พันธุ์ทนต่อการขาดโบรอน (เบญจวรรณและศันสนีย์, 2532) อย่างไรก็ตาม การใส่โบรอนนั้นจะต้องพิจารณาถึงปัจจัยหลายประการเช่น ชนิดดิน ฤดูปลูกและการจัดการต่างๆ เป็นต้น มีรายงานว่า การใส่ปูน การขาดน้ำและการเกิดน้ำขัง ทำให้ข้าวสาลีแสดงอาการเป็นหมันรุนแรงขึ้น เนื่องจากปัจจัยเหล่านี้ทำให้ความเป็นประโยชน์ของโบรอนต่อพืชลดลง (Pant et al., 1998; สุทัศน์, 2541) Rerkasem and Jamjod (1997) พบความแตกต่างระหว่างพันธุ์ข้าวสาลีในการตอบสนองต่อการขาดโบรอนและเสนอว่า การใช้พันธุ์ที่ทนทานต่อการขาดโบรอนน่าจะเป็นแนวทางการแก้ปัญหาได้ดีที่สุด Jamjod et al (1992) พบว่าสายพันธุ์ที่ได้จากการคัดเลือกและปรับปรุงพันธุ์ในประเทศไทยจำนวนหนึ่งแสดงลักษณะทนต่อการขาดโบรอนได้ดีโดยมีพันธุ์ Fang 60 เป็นพันธุ์ทนที่สุด

สำหรับข้าวบาร์เลย์นั้น เบญจวรรณและศันสนีย์ (2532) พบว่าการขาดโบรอนทำให้ผลผลิตของสายพันธุ์ BRB 1 และ BRB 2 ลดลงถึง 50% เมื่อปลูกในดินที่มีโบรอนต่ำ นอกจากนั้นยังพบว่าข้าวบาร์เลย์ในแปลงเกษตรกรบางแหล่งแสดงอาการเป็นหมัน ซึ่งอาจมีสาเหตุมาจากการขาดโบรอน อย่างไรก็ตามข้อมูลเกี่ยวกับการตอบสนองของพันธุกรรมข้าวบาร์เลย์ต่อการขาดโบรอนมีค่อนข้างจำกัด และการศึกษาในข้าวสาลีบ่งชี้ถึงความเป็นไปได้ในการแสวงหาลักษณะทนทานต่อการขาดโบรอนได้จากสายพันธุ์ที่คัดเลือกในประเทศไทย ดังนั้น งานทดลองนี้จึงมีวัตถุประสงค์เพื่อทดสอบและประเมินความแตกต่างทางพันธุกรรมของข้าวบาร์เลย์ที่คัดเลือกในประเทศในลักษณะการตอบสนองต่อโบรอน และเพื่อเปรียบเทียบความแปรปรวนทางพันธุกรรมระหว่างข้าวบาร์เลย์กับข้าวสาลี ผลที่ได้อาจนำไปใช้เป็นแนวทางช่วยในการปรับปรุงพันธุ์สำหรับปลูกในพื้นที่ที่มีปัญหาการขาดโบรอน

อุปกรณ์และวิธีการทดลอง

1. การทดสอบเบื้องต้น

ทดลองในช่วงเดือนพฤศจิกายน 2540-กุมภาพันธ์ 2541 ใช้สายพันธุ์ข้าวบาร์เลย์จากชุดเปรียบเทียบผลผลิต (Barley Thailand Yield Nurseries 1997/98, BTYN 97/98) จำนวน 21 สายพันธุ์ ประกอบด้วยข้าวบาร์เลย์ชนิดสองแถวจำนวน 13 สายพันธุ์และข้าวบาร์เลย์ชนิดหกแถวจำนวน 8 สายพันธุ์ ปลูกในสภาพขาดโบรอนใน sand culture และไม่ขาดโบรอนในแปลง ใช้ข้าวสาลีพันธุ์ Fang 60 ซึ่งทนต่อการขาดโบรอน (B efficient) และสายพันธุ์ SW 41 ซึ่งไม่ทนในระดับปานกลางต่อการขาดโบรอน (moderately B inefficient) (Rerkasem and Jamjod, 1997) เป็นพันธุ์เปรียบเทียบมาตรฐาน โดยมีรายละเอียดของงานทดลองดังนี้

1.1 สภาพไม่ขาดโบรอนในแปลงทดลอง

ปลูกที่แปลงทดลองภาควิชาพืชไร่ คณะเกษตรศาสตร์ มหาวิทยาลัยเชียงใหม่ วางแผนการทดลองแบบ Randomized Complete Block มี 3 ซ้ำแต่ละสายพันธุ์ปลูกแบบโรยเป็นแถว แถวยาว 2 ม. ระยะระหว่างแถว 25 ซม. ปลูก 4 แถวเมื่อถึงระยะเก็บเกี่ยวสุ่มเก็บแปลงละ 20 รวง นำมาตรวจนับดัชนีการติดเมล็ด (Grain Set Index, GSI%) เพื่อใช้เป็นตัวบ่งชี้ระดับการตอบสนองต่อโบรอน (Anantawiroon et al., 1997) โดยจำแนกเป็น

- GSI ข้าวสาลี = % การติดเมล็ดจากดอกร้างสองดอก (basal florets) ของแต่ละช่อดอกย่อย (spikelet) บริเวณกลางรวง จำนวน 10ช่อดอกย่อย
- GSI ข้าวบาร์เลย์ชนิดหกแถว = % การติดเมล็ดจากดอกร้างสองดอกของแต่ละช่อดอกย่อย บริเวณกลางรวงจำนวน 10ช่อดอกย่อย
- GSI ข้าวบาร์เลย์ชนิดสองแถว = % การติดเมล็ดจากดอกกลางของแต่ละช่อดอกย่อยบริเวณกลางรวง จำนวน 10 ช่อดอกย่อย

1.2 สภาพขาดโบรอนใน sand culture

ปลูกในทรายบรรจุในถังซีเมนต์ขนาด 1.5x3.0x0.5 ม.^{3} วางแผนการทดลองแบบ Randomized Complete Block มี 3 ซ้ำแต่ละสายพันธุ์ปลูกเป็นแถวโดยให้ระยะห่างระหว่างแถว 6

ซม. แต่ละแถวปลูก 6 หลุม ระยะระหว่างหลุม 6 ซม. รดด้วยสารละลายธาตุอาหารครบยกเว้นโบรอน หลังงอกถอนแยกให้เหลือ 1 ต้นต่อหลุม เมื่อถึงระยะเก็บเกี่ยวสุ่มเก็บตัวอย่างรวงจำนวน 2 รวงต่อต้น นำมานับหาค่า GSI วิเคราะห์ผลการทดลองโดยวิเคราะห์ความแปรปรวนและเปรียบเทียบกับ Fang 60 และ SW 41

2. <u>ศึกษาการตอบสนองของสายพันธุ์ในระดับโบรอนแตกต่างกัน</u>

ปลูกที่แปลงทดลองศูนย์วิจัยเพื่อเพิ่มผลผลิตทางเกษตร มหาวิทยาลัยเชียงใหม่ ในดินชุดสันทราย (HWSB 0.10-0.14 mgB ha $^{-1}$) ระหว่างเดือนพฤศจิกายน 2541 - กุมภาพันธ์ 2542 วางแผนการทดลองแบบ split plot มี 4 ซ้ำจัดระดับโบรอนโดยการใส่ปุ๋นขาวหรือโบรอนลงในดินก่อนปลูก ให้ระดับโบรอนเป็น main plot มี 4 ระดับดังนี้

BL: ใส่ปูนขาวอัตรา 2 ตันต่อเฮคตาร์เพื่อเพิ่มความรุนแรงของการขาดโบรอน (เบญจวรรณและศันสนีย์, 2532)

B0: ไม่ใส่ปูนและโบรอน

B1: ใส่โบรอนในรูปบอแรกซ์อัตรา 1 กก. บอแรกซ์ต่อเฮคตาร์

B2: ใส่โบรอนในรูปบอแรกซ์อัตรา 10 กก. บอแรกซ์ต่อเฮคตาร์

ส่วน subplot ได้แก่สายพันธุ์ข้าวบาร์เลย์และข้าวสาลีจำนวน 12 สายพันธุ์ ประกอบด้วย สายพันธุ์ข้าวบาร์เลย์จากการทดสอบเบื้องต้นที่มีความแตกต่างในการทนต่อการขาดโบรอน (BRB 9604, BRB 9642, BRB 2, FNB: 8309-34-SMG-1-1 และ SMG 1) สายพันธุ์ BCMU 96-1, BCMU 96-9 และ SMGBL 91002 และข้าวสาลีพันธุ์ทนต่อการขาดโบรอน (Fang 60) ทนปานกลาง (BCMU 88-9) ไม่ทนปานกลาง (SW 41) และไม่ทน (Bonza) แต่ละแปลงย่อยปลูกแบบโรยเป็นแถวยาว 2.5 ม. แปลงละ 3 แถว ระยะระหว่างแถว 25 ซม. เมื่อถึงระยะสุกแก่สุ่มเก็บ 20 รวงจากแต่ละแปลงย่อย ตรวจนับจำนวนช่อดอกต่อรวง จำนวนเมล็ดต่อรวง จำนวนเมล็ดต่อช่อดอกย่อยและดัชนีการติดเมล็ด ส่วนที่เหลือภายในแปลงได้เก็บเกี่ยวรวมแล้วนำไปนวดและชั่งหาน้ำหนักผลผลิตเมล็ดรวม

ผลการทดลองและวิจารณ์ผล

1. <u>การทดสอบเบื้องต้น</u>

การทดสอบความสามารถในการทนต่อการขาดโบรอนของข้าวบาร์เลย์ชุด BTYN 97/98 พบว่าเมื่อปลูกในดินที่ไม่ขาดโบรอน ข้าวสาลี SW 41 ติดเมล็ดตามปกติไม่แสดงอาการขาดโบรอน และข้าวบาร์เลย์ส่วนใหญ่ติดเมล็ดเป็นปกติเช่นกัน โดยมีดัชนีการติดเมล็ด (GSI) มากกว่า 80% ขึ้นไป (Table 1) แต่เมื่อนำสายพันธุ์ข้างต้นมาปลูกทดสอบในสภาพไม่ใส่โบรอนใน sand culture พบว่าข้าวสาลีพันธุ์ Fang 60 ติดเมล็ดเป็นปกติ มีค่า GSI 98% ในขณะที่สายพันธุ์ SW 41 ติดเมล็ดเพียง 65% สำหรับข้าวบาร์เลย์นั้นพบความแตกต่างของค่า GSI ภายในกลุ่มที่นำมาทดสอบทั้งชนิดสองแถวและหกแถว เมื่อเปรียบเทียบกับข้าวสาลี Fang 60และ SW 41 ข้าวบาร์เลย์ชนิดสองแถวมีระดับความแตกต่างของการทนทานต่อการขาดโบรอนมากกว่าชนิดหกแถว (GSI อยู่ระหว่าง 5-90%) โดยสามารถแบ่งสายพันธุ์ชนิดสองแถวได้เป็น 4 กลุ่มได้แก่

กลุ่มที่ 1 ติดเมล็ดปกติเช่นเดียวกับ Fang 60 ได้แก่สายพันธุ์ BRB 9604

กลุ่มที่ 2 ค่า GSI อยู่ระหว่าง Fang 60 และ SW 41 ได้แก่สายพันธุ์ BBR 9624 และ BRB 9

กลุ่มที่ 3 ติดเมล็ดเท่ากับ SW 41

กลุ่มที่ 4 ติดเมล็ดน้อยกว่า SW 41

สำหรับชนิดหกแถวพบว่ามี GSI ระหว่าง 25-55% สามารถแบ่งได้เพียงสองกลุ่มคือ

กลุ่มที่ 1 ติดเมล็ดเท่ากับ SW 41 ได้แก่สายพันธุ์ FNBL 8309-34-SMG-1-1, FNBL 8306-BC-SMG-1-1 และ FNBL #140

กลุ่มที่ 2 ติดเมล็ดน้อยกว่า SW 41

2. <u>การตอบสนองของสายพันธุ์ข้าวบาร์เลย์ต่อระดับโบรอนในดิน</u>

เมื่อนำข้าวบาร์เลย์และข้าวสาลีที่มีความทนทานต่อการขาดธาตุโบรอนต่างกันจำนวน 12 สายพันธุ์ มาปลูกในดินที่มีระดับของโบรอนต่างกัน 4 ระดับ พบว่า โบรอนไม่มีผลต่อจำนวนช่อดอกต่อรวงของข้าวบาร์เลย์และข้าวสาลี (Table 2) ในขณะที่พบปฏิกริยาร่วม (interaction) ระหว่างระดับโบรอนและพันธุ์ในลักษณะจำนวนเมล็ดต่อรวง (Figure 1) จำนวนเมล็ดต่อช่อดอก (Figure 2) GSI (Figure 3) และผลผลิต (Figure 4) โดยพบว่าการขาดโบรอนมีอิทธิพลต่อลักษณะเหล่านี้ในข้าวสาลีและข้าวบาร์เลย์บางพันธุ์ แต่ไม่มีผลต่อ Fang 60, BRB 9624, BRB 9604 และ FNBL 8309 การวัดความสามารถในการทนต่อการขาดโบรอนโดยใช้ค่า GSI พบว่าข้าวสาลีพันธุ์เปรียบเทียบ 4 สายพันธุ์

แสดงระดับความทนทานต่อการขาดโบรอนเช่นเดียวกับงานทดลองที่ได้การศึกษามาแล้ว (Rerkasem and Jamjod, 1997) กล่าวคือ พันธุ์ Fang 60 ทนต่อการขาดโบรอนได้สูงสุด สายพันธุ์ CMU 88-9 ทนได้ปานกลาง สายพันธุ์ SW 41 ไม่ทนปานกลางและพันธุ์ Bonza ทนต่อการขาดโบรอนได้น้อยที่สุด (Figure 4) และพบว่าบาร์เลย์สายพันธุ์ BRB 9624, BRB 9604 และ FNBL 8309 ทนต่อการขาดโบรอนได้ดีในระดับเดียวกับข้าวสาลีพันธุ์ Fang 60 ส่วนข้าวบาร์เลย์สายพันธุ์ SMGBL 91002 ไม่ทนต่อการขาดโบรอนในระดับเดียวกับข้าวสาลี SW 41 สำหรับข้าวบาร์เลย์สายพันธุ์ SMG 1 ไม่ทนที่สุดในระดับใกล้เคียงกับข้าวสาลีพันธุ์ Bonza ส่วนอีกสามสายพันธุ์ที่เหลือคือ BCMU 96-9, BCMU 96-1 และ BRB 2 นั้นมีลักษณะการตอบสนองต่อระดับโบรอนที่แตกต่างออกไปโดยในระดับโบรอนต่ำ ๆ (BL และ B0) นั้นจะไม่ทนต่อการขาดโบรอนใกล้เคียงกับข้าวสาลี SW 41 และ Bonza แต่ในระดับโบรอนที่สูงขึ้นไปจนพอเพียง (B2) สายพันธุ์เหล่านี้ยังแสดงการขาดโบรอนอยู่

3. การประยุกต์ใช้ในงานปรับปรุงพันธุ์

งานศึกษาครั้งนี้แสดงให้เห็นว่ามีความแตกต่างทางพันธุกรรมในการตอบสนองต่อการขาดโบรอนในข้าวบาร์เลย์ จากการทดสอบเบื้องต้นใน sand culture พบว่าข้าวบาร์เลย์ชนิดสองแถว BRB 9624 และ BRB 9604 สามารถติดเมล็ดได้ดีในสภาพที่มีโบรอนต่ำและเมื่อนำมาปลูกทดสอบในแปลงปลูกปีถัดไป จึงสามารถใช้เป็นพันธุ์แนะนำสำหรับปลูกในดินที่มีโบรอนต่ำ ๆ หรือใช้เป็นแหล่งพันธุกรรมในการปรับปรุงพันธุ์ข้าวบาร์เลย์ให้มีความทนทานต่อการขาดโบรอนได้ ส่วนข้าวบาร์เลย์สายพันธุ์ FNBL 8309 ไม่ทนต่อการขาดโบรอนในระดับเดียวกับข้าวสาลี SW 41 เมื่อปลูกใน sand culture แต่เมื่อนำมาปลูกในดินพบว่ามีความทนทานได้สูงในระดับเดียวกับข้าวสาลีพันธุ์ Fang 60 ทั้งนี้เนื่องจากกลไกการดูดธาตุอาหารในดิน ใน sand culture หรือใน solution culture อาจแตกต่างกันได้ (Marschner, 1995) อย่างไรก็ตามควรมีการทดสอบความทนทานของสายพันธุ์ FNBL 8309 ก่อนนำไปใช้

แหล่งพันธุกรรมของความทนทานต่อการขาดโบรอนในข้าวบาร์เลย์ที่พบนั้นได้มาจากสายพันธุ์ที่ประยุกต์มาจากสายพันธุ์หรือประชากรจาก CIMMYT และนำมาคัดเลือกและปรับปรุงพันธุ์ในประเทศไทย ผลการทดลองครั้งนี้สอดคล้องกับผลการศึกษาในข้าวสาลีที่พบว่าสายพันธุ์ในประเทศไทยที่คัดเลือกจากประชากรหรือแหล่งพันธุกรรมจาก CIMMYT นั้นมีพันธุกรรมที่ควบคุมความทนทานต่อการขาดโบรอนปะปนอยู่ (Rerkasem and Jamjod, 1997) อย่างไรก็ตาม ถึงแม้จะมีแหล่งพันธุ

กรรมอยู่ในประชากรอยู่แล้วแต่พบว่าสายพันธุ์ดี (advanced lines) ในชุดทดสอบเปรียบเทียบพันธุ์ภายในประเทศหรือระหว่างประเทศนั้น มีสายพันธุ์ที่มีความทนทานต่อการขาดโบรอนได้ดีอยู่ในสัดส่วนน้อยมาก (Jamjod and Rerkasem, 1998) เนื่องจากพื้นที่ส่งเสริมการปลูกธัญพืชเมืองหนาวในประเทศไทยส่วนใหญ่มีรายงานของการขาดโบรอนในดินกระจายอยู่ทั่วไป จึงควรจะเพิ่มลักษณะทนทานต่อการขาดโบรอนไว้ในเป้าหมายของงานปรับปรุงพันธุ์อีกลักษณะหนึ่ง นอกเหนือไปจากการเพิ่มผลผลิต ความต้านทานต่อโรคแมลงและคุณภาพ การตรวจสอบระดับความทนทานต่อการขาดโบรอนสามารถทำได้ง่ายโดยตรวจนับค่า GSI ในดินที่มีโบรอนต่ำหรือใน sand culture โดยปลูกพันธุ์มาตรฐานที่ทราบระดับความทนทานต่อการขาดโบรอนร่วมด้วยจะทำให้เพิ่มความแม่นยำในการตรวจสอบและทราบระดับของการตอบสนองของพันธุ์หรือประชากรที่ทดสอบและปรับปรุงเพื่อส่งเสริมแก่เกษตรกรในพื้นที่เป้าหมายต่อไป

สรุปผลการทดลอง

1. มีความแตกต่างทางพันธุกรรมในการตอบสนองต่อการขาดโบรอน ในข้าวบาร์เลย์ที่คัดเลือกในประเทศไทย ลักษณะที่ตอบสนองได้แก่ จำนวนเมล็ดต่อรวง จำนวนเมล็ดต่อช่อดอก ดัชนีการติดเมล็ด และผลผลิต
2. ในชุดเปรียบเทียบผลผลิต BTYN 97/98 มีจำนวนสายพันธุ์ข้าวบาร์เลย์ที่ทนต่อการขาดโบรอนน้อยกว่าข้าวสาลีสายพันธุ์ SW 41 ถึง 38% และน้อยกว่า Fang 60 ถึง 86% แสดงให้เห็นว่าสายพันธุ์ข้าวบาร์เลย์ส่วนใหญ่ไม่ทนต่อการขาดโบรอน
3. สายพันธุ์ข้าวบาร์เลย์ที่มีความทนทานต่อการขาดโบรอนได้สูงใกล้เคียงกับข้าวสาลีพันธุ์มาตรฐานได้แก่ BRB 9604 และ BRB 9624 ซึ่งสามารถใช้แนะนำให้ปลูกในพื้นที่ ๆ มีปัญหาหรือใช้เป็นสายพันธุ์พ่อแม่ในโครงการปรับปรุงพันธุ์ต่อไป

คำนิยม

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Table 1. Response of advanced lines from Barley Thailand Yield Nurseries 1997/98 grown in sand culture and in the field.

Note : Two bread wheat genotypes, Fang 60 (B efficient, E) and SW 41 (moderately B inefficient, MI) were included as checks.

Genotypes	Origin[a]	Sand culture (B deficient)			Field (B sufficient)		
		GSI[b]	% of checks		GSI	% of checks	
		(%)	Fang 60	SW 41	(%)	Fang 60	SW 41
Two-row barley							
BRB 9604	BRB	90.0	91	138*	93.1	100	96
BRB 9624	BRB	85.3	87	131	94.7	102	98
BRB 9	BRB	79.9	81	123	95.0	102	98
BRB 9609	BRB	75.2	76*	115	94.7	102	98
BRB 10	BRB	74.5	76*	114	88.7	95	92
BRB 11	BRB	72.5	74*	111	94.7	102	98
LARTC-BL9101	LMP	64.1	65**	98	98.3	106	102
BRB 9621	BRB	61.5	62**	94	85.7	92**	89***
LARTC-BL9119	LMP	60.7	62**	93	94.4	102	98
LARTC-BL9406	LMP	47.9	49***	73	85.0	91**	88***
SMGBL 94026	SMG	42.3	43***	66*	99.0	106*	102
LARTC-BL9410	LMP	40.4	41***	62*	71.3	76***	74***
SMGBL 94003	SMG	4.8	5*	8***	87.5	94	91*
Six-row barley							
FNBL 8309-34-SMG-1-1	SMG	55.2	58***	85	97.0	104	100
FNBL 8306-BC-SMG-1-1	SMG	46.5	47***	71	96.2	103	100
FNBL #140	SMG	45.9	47***	70	96.2	103	100
FNBL 84404-4-SMG-1-1-1	SMG	38.9	40***	60**	93.3	100	97
FNBL 8403-6-SMG-1-2-1	SMG	37.0	38***	57**	96.2	103	100
FNBL 8403-17-SMG-1-1-1	SMG	34.5	35***	53**	93.7	101	97
SMG 1	SMG	31.9	32***	49**	98.7	106*	102
BRB 2	BRB	24.7	25***	38***	91.5	98	95
Wheat (checks)							
Fang 60 (E)		98.3	100	151**	93.0	100	96
SW 41 (MI)		65.1	66**	100	96.6	104	100

BRB = Boon Rawd Brewery Co. Ltd.

[a] LMP = Lampang Agricultural Research Training Center

SMG = Samoeng Upland Rice and Temperate Cereals Experiment Station.

[b] Grain Set Index (%)

*, ** and *** Significantly different from check cultivars at $p<0.05$, 0.01 and 0.001, respectively.

Table 2. Number of spikelets spike^{-1} of barley and bread wheat genotypes grown in four levels of B.

Genotypes	B treatments				Mean[a]
	BL	B0	B1	B2	
Two row barley					
BRB 9624	14.2	14.9	15.6	15.5	15.0 b
BRB 9604	16.5	15.9	15.6	15.9	16.0 cd
SMGBL 91002	21.1	21.5	21.4	20.9	21.2 f
BCMU 96-9	23.8	24.1	25.5	24.6	24.5 g
Six row barley					
FNBL 8309	13.6	13.0	13.6	13.2	13.3 a
SMG 1	14.4	14.9	15.4	15.0	14.9 b
BCMU 96-1	17.7	17.1	18.2	17.5	17.6 e
BRB 2	16.2	16.9	17.1	16.5	16.7 d
Bread wheat					
Fang 60	15.0	15.8	16.6	15.8	15.0 bcd
CMU 88-9	16.4	16.1	17.2	15.7	16.4 d
SW 41	17.3	17.2	18.8	17.6	17.7 e
Bonza	15.1	14.7	16.5	15.4	15.4 bc

F test : B^{ns}, G***, BxG^{ns}, *** significant at p<0.001

[a] Mean within a column with different letters are differ significantly at p = 0.05 with LSD.

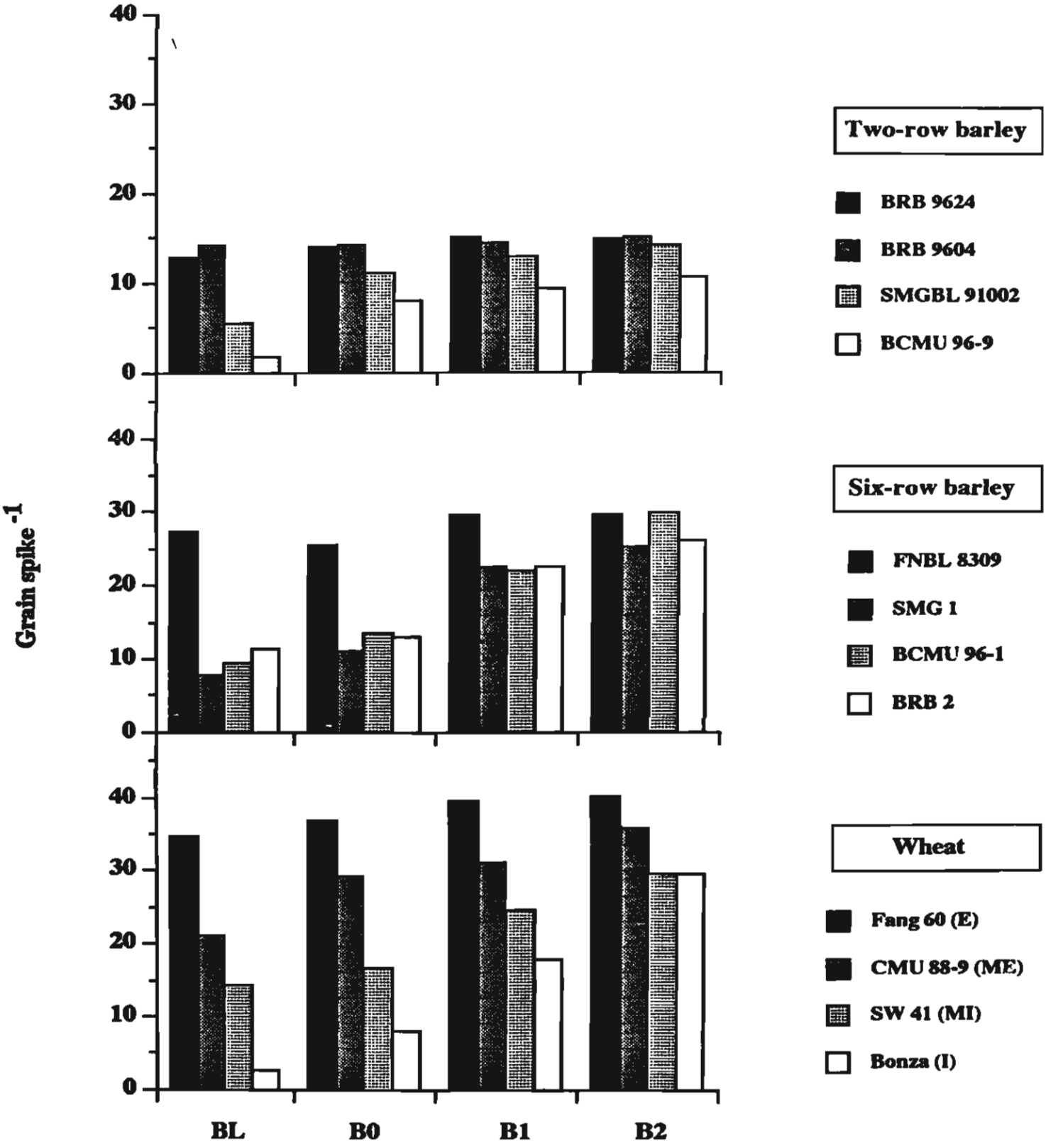

Figure 1 Effect of B treatment (B) on number of grains spike^{-1} of barley and bread wheat genotypes (G). B x G significant at $p < 0.001$. $LSD_{0.05} = 6.5$.

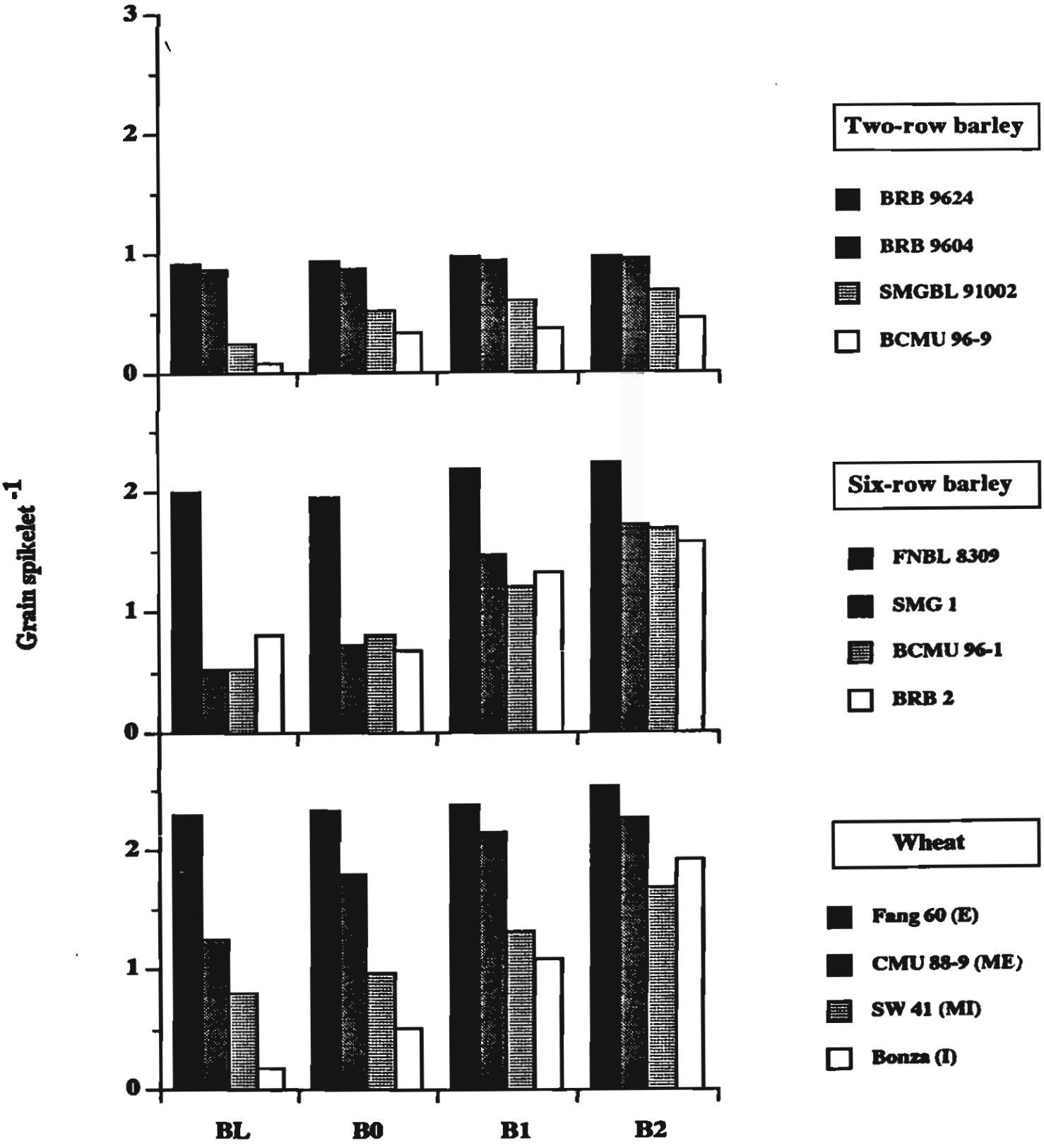

Figure 2 Effect of B treatment (B) on number of grains spikelets^{-1} of barley and bread wheat genotypes (G). B x G significant at $p < 0.001$. $LSD_{0.05} = 0.4$.

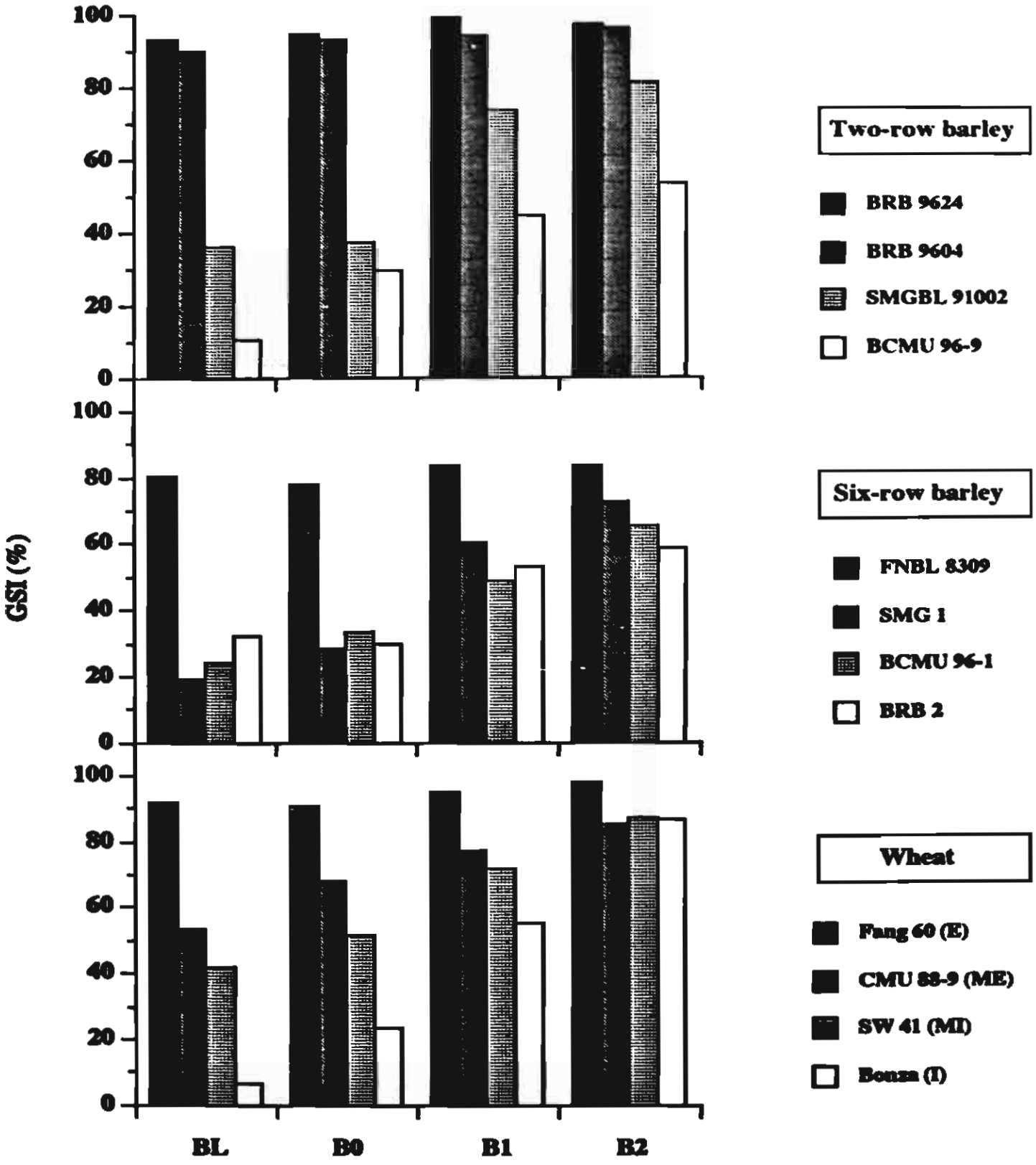

Figure 3 Effect of B treatment (B) on Grain Set Index (%) of barley and bread wheat genotypes (G). B x G significant at $p < 0.001$. $LSD_{0.05} = 16.9$.

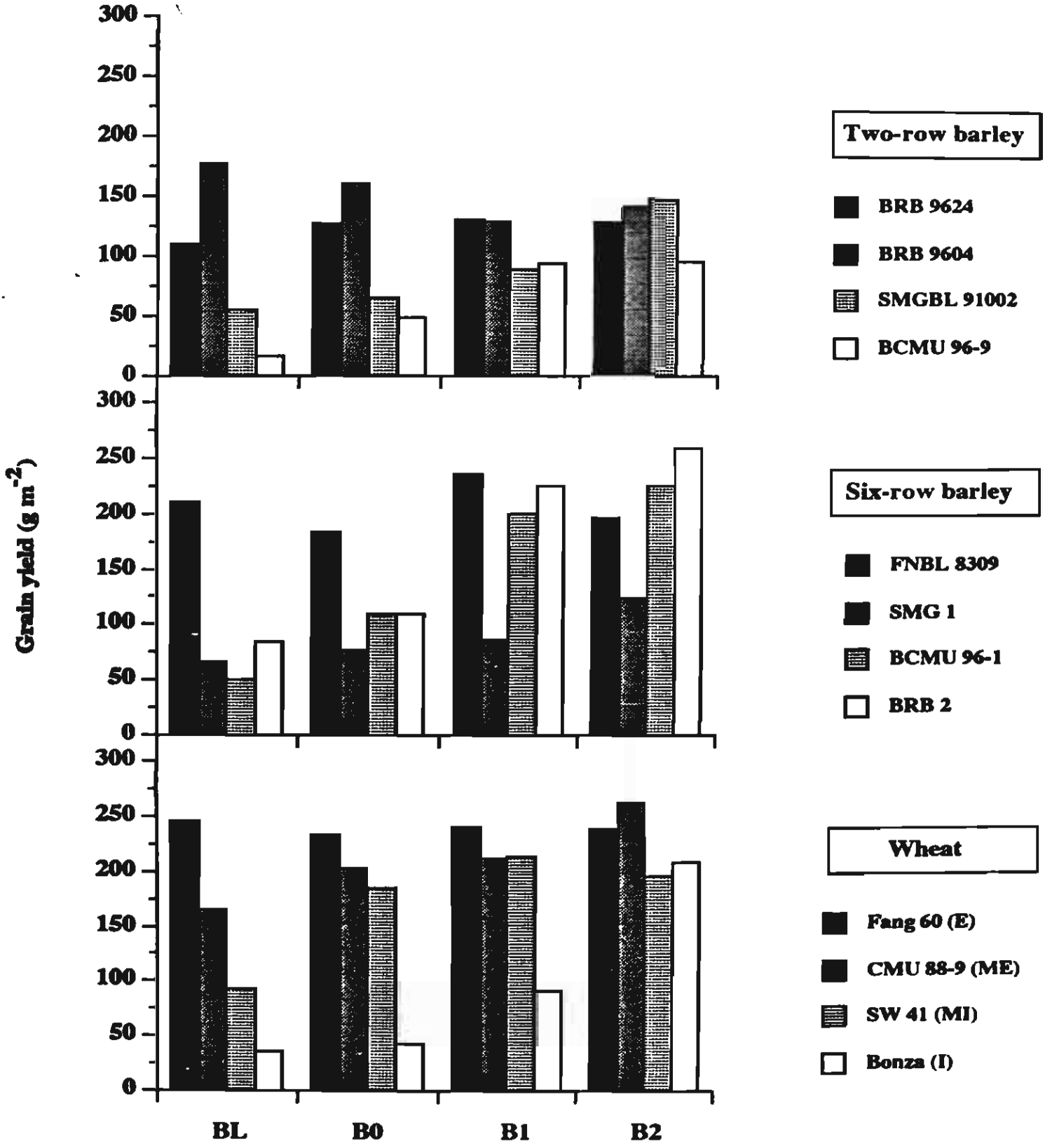

Figure 4 Effect of B treatment (B) on grain yield (g m^{-2}) of barley and bread wheat genotypes (G). B x G significant at $p < 0.001$. $LSD_{0.05} = 65$.