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## Leaf gas exchange, reproductive development, physiological and nutritional changes of peanut as influenced by boron

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### ABSTRACT

Boron application at proper concentration is necessary to enhance the leaf gas exchange, physiological growth, reproductive development and nutritional improvement of crops. Therefore, an experiment was conducted to study the effects of boron to evaluate the effect on the leaf gas exchange, reproductive development, physiological and nutritional changes of peanut. Treatments comprised six levels of boron (B), viz., B<sub>1</sub> (0 ppm), B<sub>2</sub> (0.5 ppm), B<sub>3</sub> (1 ppm), B<sub>4</sub> (2 ppm), B<sub>5</sub> (4 ppm) and B<sub>6</sub> (8 ppm). Results revealed that the vegetative growth, physiological growth parameters, leaf gas exchange, reproductive characters, peg strength, shelling (%) and nutritional elements were increased for boron application. Some vegetative, physiological and reproductive traits are positively correlated with each other. Thus, this finding showed that boron can be used to culture peanut as it provides high yield and nutritional properties.

### ARTICLE HISTORY

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### KEYWORDS

Leaf chlorophyll content; photosynthesis; yield; peg strength; chemical composition

### Introduction

Peanut has become an important oil seeds crop in every country (Onemli 2012). Boron is a key element needed by the peanut plant for nutrition and growth, and it aids in improving the development and yield of each crop (Quamruzzaman et al. 2017b). Boron is used to regulate the plants carbohydrate metabolism. This plays a significant role in forming the seeds and in protein synthesis (BARC 2005). Boron has an important role in stigma receptive to increase pollination by making pollen grain fertile (Kaisher et al. 2010). It also influences the ability to retain flower and fruit setting in peanuts (Zhang 2001; Quamruzzaman et al. 2017c). As a result, boron would increase the pod yield of peanuts (Quamruzzaman et al. 2016a). Kabir et al. (2013) stated that boron is responsible for producing healthier seeds in peanut. This micronutrient has been used to improve the quality of peanut seeds. Protein, oil and vitamin E content are some of the qualities to successfully improved by the use of boron (Quamruzzaman et al. 2016b, 2017a). It is believed that the proper use of boron nutrition will improve the crop yield and quality. An understanding of the proper use and supply of boron is important to achieve sustainable agriculture. Mistake in applying this micronutrient could result in serious loss of yield of crops. It is imperative to apply the proper balance of boron as using too much could have a toxic effect in the root zone (Çikili et al. 2015).

Photosynthetic rate depends on many different factors including the thickness of leaves (Kalariya et al. 2015), age of leaves (Nautiyal et al. 1999) and availability of nutrient and water (Rahman et al. 2012). Boron nutrition helps to facilitate and increase the photosynthesis process. This in turn increases the passage of CO<sub>2</sub> thru the stomata, and transpiration of water from the leaves of the peanut plant

(Quamruzzaman et al. 2017a). The number of active stomata also increase with proper application of boron (Pinho et al. 2010). Proper supply of boron has a definitive effect on leaf gas exchange, growth, physiology, yield, and quality of peanut. It is imperative to determine the optimal amount of boron to apply to the peanut plant.

The above studies suggested that the boron had a pronounce effect on physiological growth, yield and nutritional value of peanut. Therefore, the present study was conducted to identify the leaf gas exchange, reproductive development, physiological and nutritional changes of peanut as influenced by boron.

### Materials and methods

#### Experimental site and plant materials



The pot experiments were conducted at the Sher-e-Bangla Agricultural University, Dhaka from between March and July of 2016 and 2017. Bangladesh Agricultural Research Institute Chinabadam 8 cultivar was used as a test crop in this experiment.

#### Experimental design and treatments

A completely randomized design (CRD) with three replications were used in this study. Six levels of boron (B) application, viz., B<sub>1</sub> (0 ppm), B<sub>2</sub> (0.5 ppm), B<sub>3</sub> (1 ppm), B<sub>4</sub> (2 ppm), B<sub>5</sub> (4 ppm) and B<sub>6</sub> (8 ppm), were used in these replications.

#### Growth environment

Eighteen crates (24 L pots) were used for cultivating the peanut plants. Coco peat and broken bricks filled each crate at

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the ratio of 60:40 (v/v), respectively. Rahman and Inden (2012) solution ( $\frac{3}{4}$  strength) was used in this experiment as a standard where boron [Source: boric acid (16.5% boron)] was applied as per treatments. This solution was applied using the drip irrigation system to ensure equal amounts were received by each plant. The pH and electrical conductivity were maintained at approximately 6.0 and 3.0 dS/cm, respectively, in the nutrition solutions. Temperatures were maintained between 27.38°C (maximum) and 15.38°C (minimum) for an optimum growth condition. Reparative humidity of 63.75% and rainfall of 20.95 mm was recorded during the experiment.

### Data collection

An experimental unit consisted of three plants. Data was collected the following growth parameters: plant height, number of branches plant<sup>-1</sup>, leaf area (LA); physiological parameters, i.e. relative water content (RWC), SPAD chlorophyll meter reading (SCMR), number of stomata (abaxial surface and adaxial surface); leaf gas exchange including the transpiration (E), stomatal conductance (g<sub>s</sub>), photosynthetic rate (P<sub>N</sub>); reproductive development characters, i.e. number of pegs plant<sup>-1</sup>, number of pods plant<sup>-1</sup>, 100 seeds weight, pod dry weight plant<sup>-1</sup>. The nutritional parameters, i.e. sodium, potassium, calcium, magnesium, iron, zinc was measured along with peg strength and shelling percentage.

### Relative water content

The following equation:  $RWC (\%) = (FW - DW) / (TW - DW) \times 100$  was used to measure each component. FW is the samples fresh weight, TW is the samples turgid weight and DW is the samples dry weight

### Record of stomata number

One square cm block from the third fully expanded leaf, one square centimeter lamina was taken from the apex of a 60 day old plants from each experimental unit. A fixative mix containing glacial acetic acid and ethanol in 3:1 volume/volume (v/v) ratio was used to fix and clear each leaf sample for surface studies. These lamina samples were stained with lactophenol cotton blue and observed under the compound microscope (both the surfaces).

### Record of SCMR value

Three plants were used to record SCMR. SCMR of individual plants was taken on leaflets of third leaf at 60 days after sowing.

### Gas exchange parameter measured

The P<sub>N</sub>, E and g<sub>s</sub> were measured using the LCpro portable photosynthetic system as described by Rajaona et al. (2013). The gas exchange parameters were recorded both in vegetative and reproductive growth stage during morning hours (between 10:00 and 12:00 h) to get accurate result (Quamruz-zaman et al. 2017a).

### Peg strength

Peg tensile strength was measured with a Shimpo DFS-50 digital force gauge as described by Chapin and Thomas (2005).

### Methods of mineral elements assessment

The dry ash method as well as Asibuo et al. (2008) procedure was used to assess the mineral elements.

### Data analysis

Data was recorded and processed over two growing seasons and analyzed using SPSS (Version 20.0) and the means separated using Tukey's test a  $P \leq .05$  (Tukey 1977).

## Result and discussions

### Vegetative growth

The vegetative growth parameters of peanuts were significantly influenced by the application of boron (Table 1). These results showed that the values for plant height, number of branches of the plant<sup>-1</sup>, and LA were high for B<sub>5</sub>, while these same traits were the lowest for control. Higher LA accelerates the production of metabolites. Prieto et al. (2007) stated that higher LA resulted in an increase in the plant's ability to intercept light. The higher the growth parameter may be linked to the 4 ppm boron which contains the required nutrients which has the ability to produce higher metabolites in peanut. This growth analysis data suggests that boron at 4 ppm in  $\frac{3}{4}$  strength of Rahman and Inden (2012) solution provided better nutrition to the plant. Moreover, the optimal supply of boron in treatment B<sub>5</sub> could have the resulted in the maximum vegetative growth.

### Physiological changes

Boron had a significant effect on the physiological attributes of peanut plants (Table 2). Treatment B<sub>5</sub> resulted in the highest RWC, SCMR and stomata (abaxial and adaxial surface). Treatment B<sub>0</sub> resulted in the lowest RWC, SCMR and stomata. These tests indicated that boron deficiency considerably reduced the physiological traits of peanuts. These results also showed that the number of stomata between the abaxial surface and adaxial surface portrayed no significant difference in all the boron test levels. However, the adequate supply of boron helped increase the physiological growth of the peanut plants. The maximum relative water content was found when stomatal numbers reached 35.73 and 35.87

**Table 1.** Effect of boron on vegetative growth of peanut.

Treatments	Plant height (cm)	No. of branches Plant <sup>-1</sup>	LA (cm <sup>2</sup> )
Boron			
B <sub>1</sub>	29.67 (±0.33) f	3.20 (±0.15) e	94.53 (±0.54) e
B <sub>2</sub>	33.43 (±0.30) e	4.80 (±0.15) d	102.48 (±0.72) d
B <sub>3</sub>	36.17 (±0.17) d	6.87 (±0.09) c	112.72 (±0.74) c
B <sub>4</sub>	39.50 (±0.30) c	7.97 (±0.09) b	116.59 (±0.68) b
B <sub>5</sub>	45.44 (±0.44) a	9.95 (±0.10) a	122.30 (±0.21) a
B <sub>6</sub>	42.87 (±0.13) b	9.53 (±0.36) a	119.88 (±0.01) a
Level of significance $P$ (5%)			
B	<0.001	<0.001	<0.001

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm.  $P$  = probability. Means were separated by Tukey's test at  $P \leq .05$ . Column having different letter(s) are statistically significant and similar letter(s) are statistically insignificant.

**Table 2.** Effect of boron on physiological changes of peanut.

Treatments	RWC (%)	SCMR	Stomatal number	
			Abaxial surface	Adaxial surface
Boron				
B <sub>1</sub>	67.42 (±0.30) f	34.50 (±0.30) f	21.81 (±0.42) e	22.07 (±0.26) e
B <sub>2</sub>	72.71 (±0.36) e	37.59 (±0.30) e	23.75 (±0.09) d	23.08 (±0.05) d
B <sub>3</sub>	76.50 (±0.30) d	39.87 (±0.47) d	26.92 (±0.51) c	27.05 (±0.05) c
B <sub>4</sub>	80.75 (±0.38) c	41.99 (±0.01) c	30.98 (±0.56) b	30.43 (±0.30) b
B <sub>5</sub>	86.49 (±0.30) a	45.90 (±0.49) a	35.73 (±0.37) a	35.87 (±0.44) a
B <sub>6</sub>	83.73 (±0.37) b	44.04 (±0.04) b	34.52 (±0.29) a	34.72 (±0.49) a
Level of significance <i>P</i> (5%)				
B	<0.001	<0.001	<0.001	<0.001

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm. *P* = probability. Means were separated by Tukey's test at *P* ≤ 0.05.

(abaxial and adaxial surface, respectively). The high values for stomatal numbers indicate that it positively responsible for highest value of relative water content (Figure 1) which is supported by the findings of Xu and Zhou (2008).

### Correlation of LA and physiological traits

A positive relation was observed between the LA and physiological attributes (Figure 2). With the increase of LA this increased the physiological traits of the peanut plant. These physiological traits were highest when the LA was 122.30 cm<sup>2</sup>. It is confirmed that 4 ppm boron with ¾ strength Rahman and Inden (2012) solution resulted in higher LA that linearly correlated directly with the physiological traits.

### Leaf gas exchange

All of the parameters were studied both in vegetative growth stage and reproductive growth stages. Results revealed that the application of boron enhanced the transpiration (*E*) and stomatal conductance (*g<sub>s</sub>*) in peanut (Table 3). The statistically significant increasing trend of *E* and *g<sub>s</sub>* showed up to B<sub>5</sub> and then decreased, the decreased trend found up to B<sub>6</sub>. Findings suggest that the increased *E* was associated with the increased *g<sub>s</sub>*. The increased numbers of *E* and *g<sub>s</sub>* obtained in this study are supported by the findings of Lu et al. (2014) and Quamruzzaman et al. (2017a). Choi et al. (2016) reported that transpiration, stomatal conductance was significantly decreased in boron deficient areas.

### Net photosynthetic rate

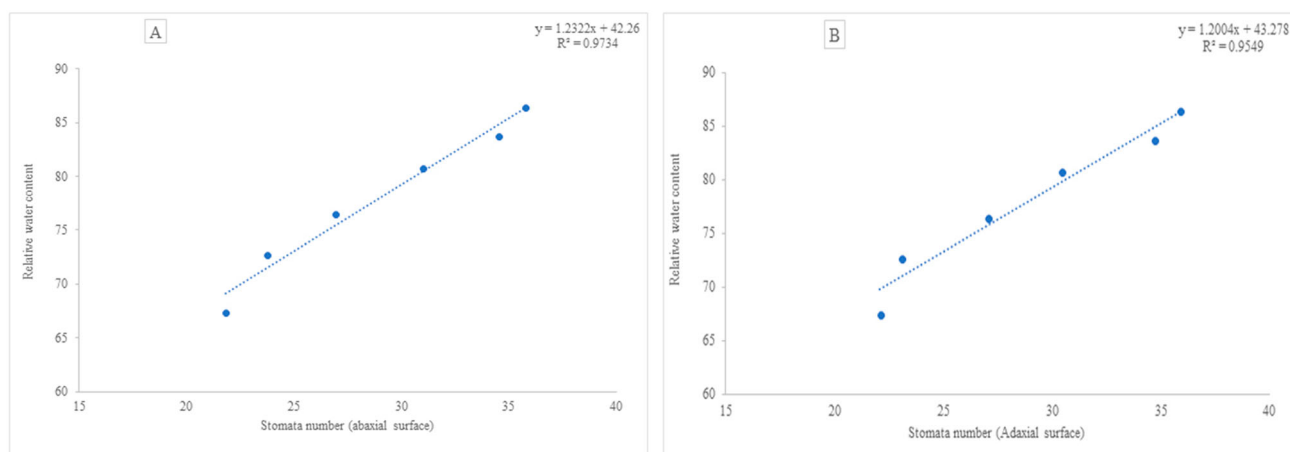
Boron application had a significant effect on net photosynthetic rate during vegetative and reproductive growth stages. Treatment B<sub>5</sub> facilitated the higher P<sub>N</sub> far more than the other treatments (Figure 3). Viewing thru the microscope revealed that the stomatal pores in the lamina of the leaves were opened at a maximum amount in the boron treated plants. A recent study showed that, gas exchange basically stomatic effects as well as photosynthesis was lead by boron application in peanut plants (Quamruzzaman et al. 2017a). Reduced stomatal number resulted in a decreased intake of CO<sub>2</sub> that can be used in carboxylation reactions (Brugnoli and Björkman 1992). With the higher stomatal numbers in plants the diffusion of CO<sub>2</sub> in the leaves increases and thus increases the rate of photosynthesis. The P<sub>N</sub> is progressively increased because of increasing stomatal number.

### Correlation of LA to leaf gas exchange

LA had a significantly positive and linear correlation with leaf gas exchange, including transpiration and stomatal conductance (Figure 4). The relationship between LA and gas exchange parameters was remarkably scattered and significant association was found. Results indicate that an increase in LA is closely associated with transpiration and stomatal conductance that also positively associated with net photosynthetic rate.

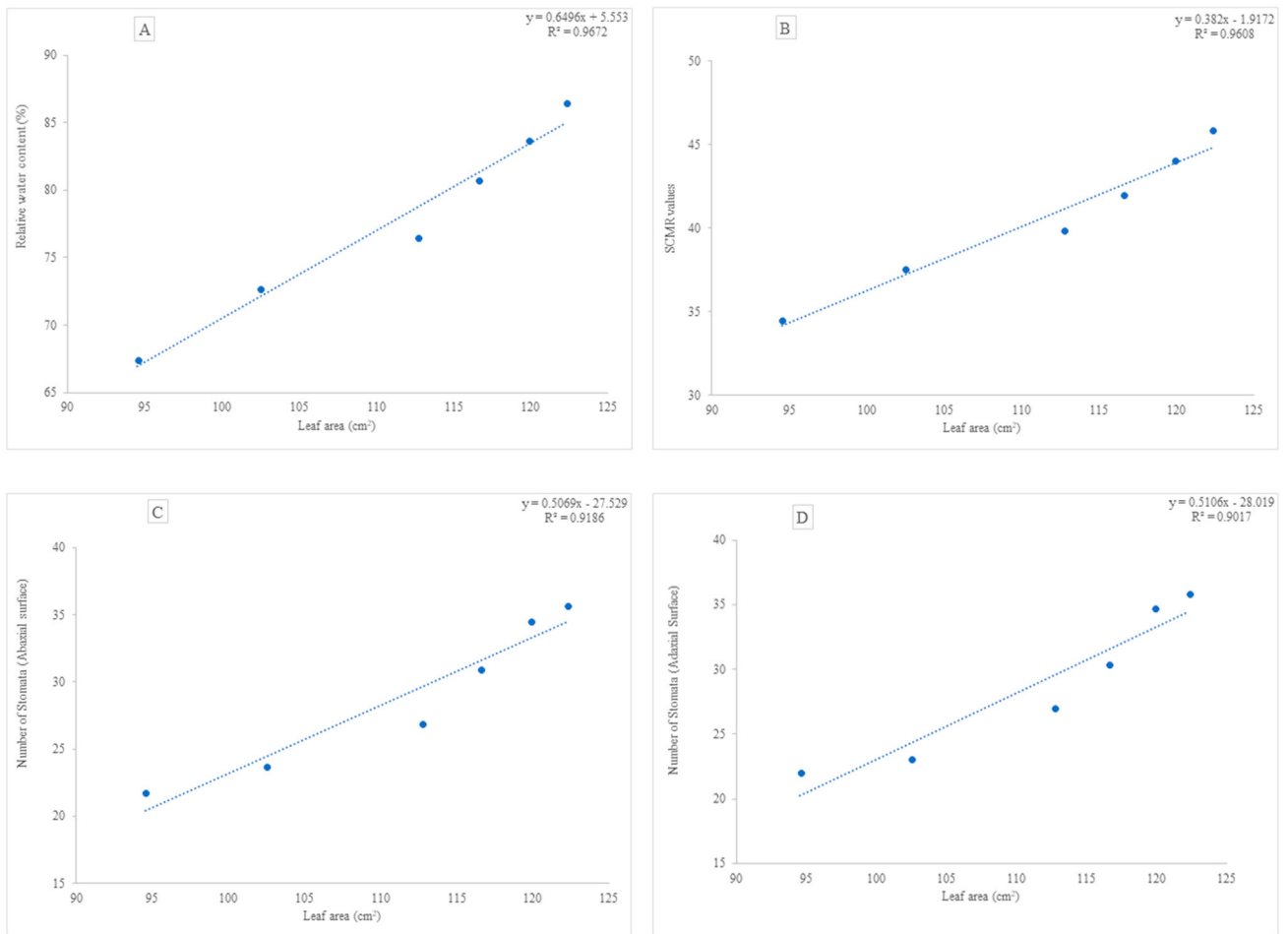
### Reproductive development

Boron application affects the reproductive development of the peanut. Significant differences were observed in a



**Figure 1.** Response of stomatal number ((A) abaxial surface of leaf in peanut and (B) adaxial surface of leaf in peanut) to relative water content.

Notes: Dots represent the values of the studies parameter for the treatments (B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm). Dotted line represents the best linear fit to the values of studied parameters. Means were separated by Tukey's test at *P* ≤ .05.



**Figure 2.** Response of LA to (A) relative water content, (B) SCMR values, (C) stomatal number in abaxial surface and (D) stomatal number in adaxial surface.

Notes: Dots represent the values of the studies parameter for the treatments (B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm). Dotted line represents the best linear fit to the values of studied parameters. Means were separated by Tukey’s test at  $P \leq .05$ .

**Table 3.** Effect of boron on transpiration (E) and stomatal conductance (g<sub>s</sub>) of peanut.

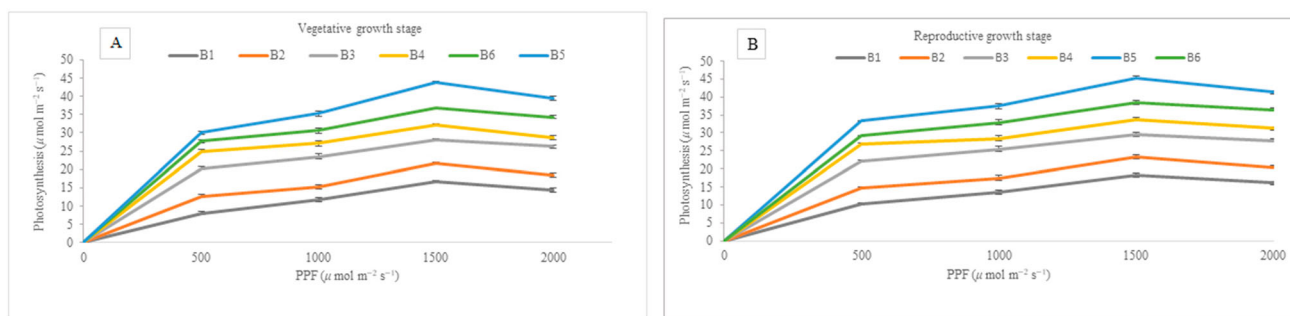
Treatments	Vegetative growth stage		Reproductive growth stage	
	E (mmol m <sup>-2</sup> s <sup>-1</sup> )	g <sub>s</sub> (mol m <sup>-2</sup> s <sup>-1</sup> )	E (mmol m <sup>-2</sup> s <sup>-1</sup> )	g <sub>s</sub> (mol m <sup>-2</sup> s <sup>-1</sup> )
Boron (B)				
B <sub>1</sub>	7.90 (±0.39) d	0.19 (±0.003) f	9.58 (±0.17) f	0.23 (±0.003) e
B <sub>2</sub>	9.89 (±0.38) c	0.30 (±0.07) e	10.74 (±0.04) ef	0.34 (±0.07) d
B <sub>3</sub>	10.41 (±0.20) c	0.34 (±0.003) d	11.13 (±0.21) de	0.39 (±0.003) c
B <sub>4</sub>	11.82 (±0.11) b	0.41 (±0.003) c	12.14 (±0.42) cd	0.47 (±0.003) b
B <sub>5</sub>	14.29 (±0.23) a	0.52 (±0.006) a	15.05 (±0.36) a	0.55 (±0.23) a
B <sub>6</sub>	12.69 (±0.24) b	0.45 (±0.003) b	13.28 (±0.17) bc	0.47 (±0.06) b
Level of significance P (5%)				
B	<0.001	<0.001	<0.001	<0.001

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm. P = probability. Means were separated by Tukey’s test at  $P \leq .05$ .

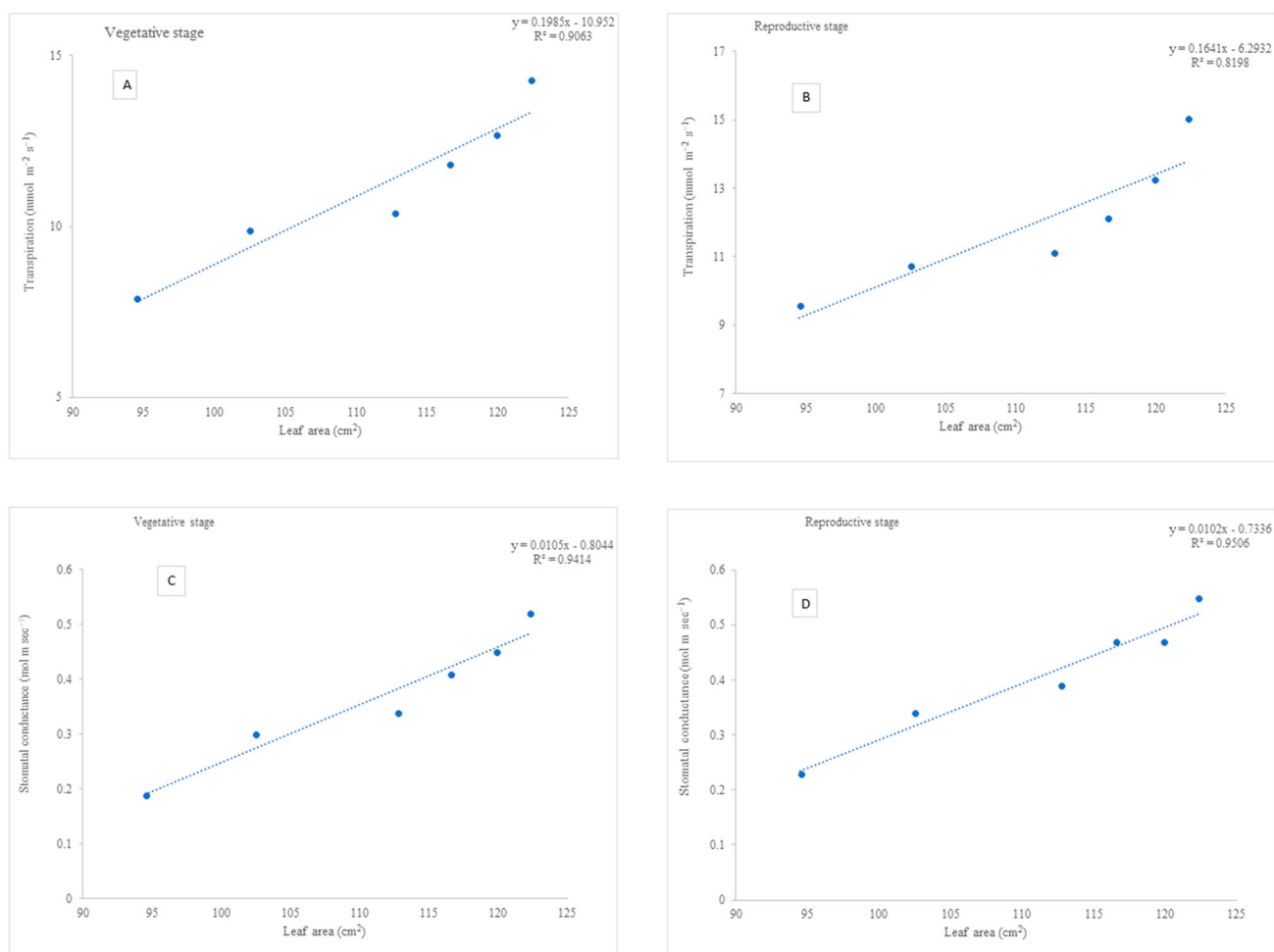
number of pegs plant<sup>-1</sup>, number of pods plant<sup>-1</sup>, 100 seeds weight and pods dry weight (mature and immature pods) plant<sup>-1</sup> as a result of boron application (Table 4). Treatment B<sub>4</sub> produced the maximum number of reproductive units. This might be because of an adequate supply of boron provided by treatment B<sub>4</sub>. Kaisher et al. (2010) reported that boron had a pronounced effect on stigma receptivity, sticky and to make the pollen grain fertile for enhancing the pollination. Therefore, the application of boron resulted in the maximum number of pegs, pods (Naiknaware et al. 2015) and pods dry weight plant<sup>-1</sup> (Quamruzzaman et al. 2016a). The present finding is consistent with their findings.

### Correlation of SCMR and reproductive development

The SCMR values are positively correlated with the reproductive development of peanut plant (Figure 5). Leaf chlorophyll reading (SPAD chlorophyll reading/SCMR value) ranged from 34.50 (at B<sub>0</sub>) to 45.90 (at B<sub>5</sub>) indicated higher reproductive development of plant. The reproductive development was higher at the point of 45.90 SCMR value. This might be attributed to dilution effect of the nutrients where most of the boron might be used for plant development. Buttery and Buzzell (1977) reported that chlorophyll content directly correlated with the photosynthetic rate as well as reproductive development.



**Figure 3.** Effect of boron on net photosynthetic rate under different photosynthetic photon flux (PPF) at vegetative (A) and reproductive (B) growth stage of peanut. Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm. Means were separated by Tukey's test at  $P \leq .05$ . Vertical bars represent the SE of the treatment means.



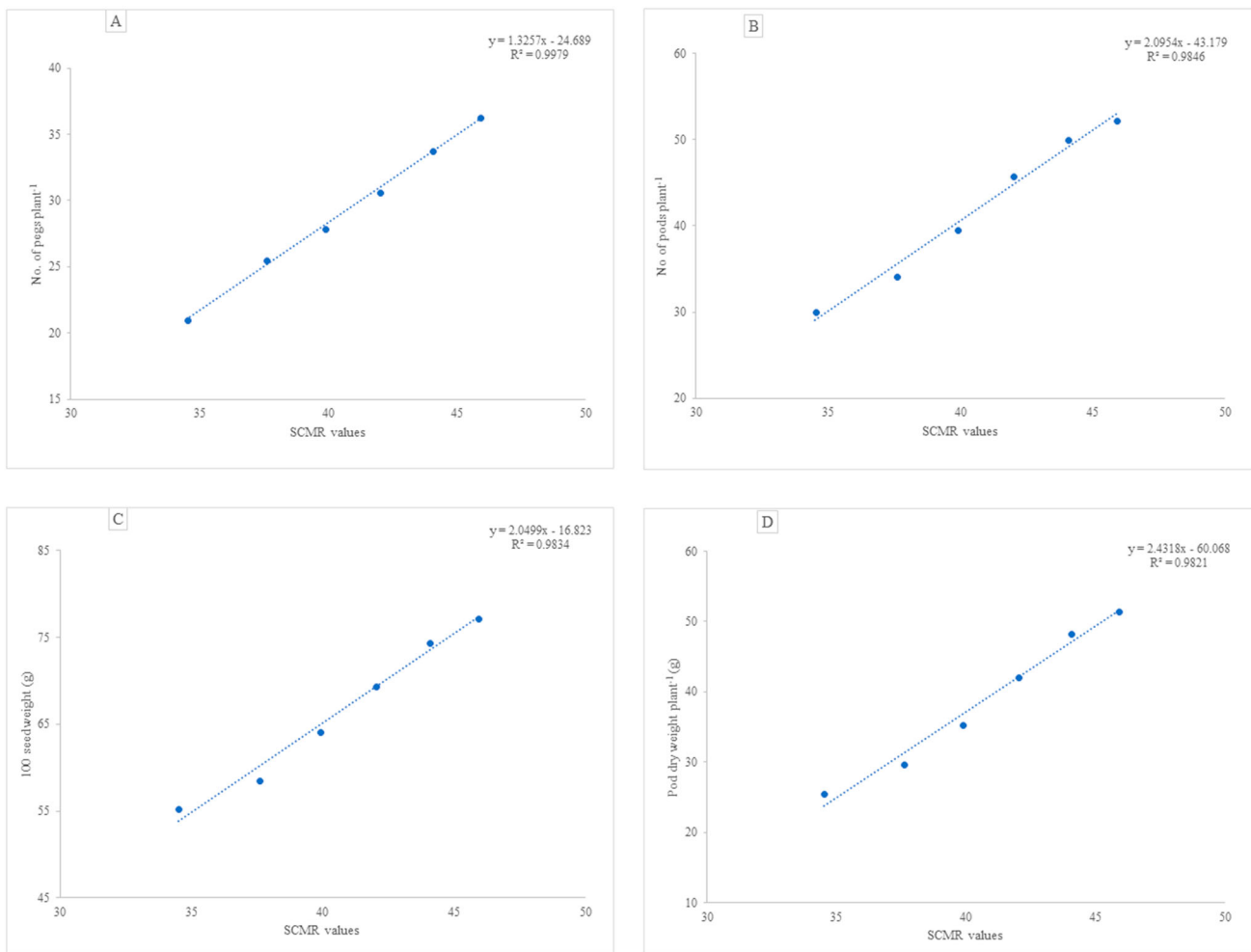
**Figure 4.** Response of LA to transpiration ((A) vegetative growth stage, (B) reproductive growth stage) and stomatal conductance ((C) vegetative growth stage, (D) reproductive growth stage).

Notes: Dots represent the values of the studies parameter for the treatments (B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm). Dotted line represents the best linear fit to the values of studied parameters. Means were separated by Tukey's test at  $P \leq .05$ .

**Table 4.** Effect of boron on reproductive development of peanut.

Treatments	No. of pegs plant <sup>-1</sup>	No. of pods plant <sup>-1</sup>	100 seed weight (g)	Pods dry weight plant <sup>-1</sup> (g)
Boron				
B <sub>1</sub>	21.00 (±0.58) f	30.08 (±0.58) e	55.33 (±0.88) f	25.53 (±0.44) f
B <sub>2</sub>	25.52 (±0.30) e	34.12 (±0.68) d	58.57 (±0.30) e	29.70 (±0.63) e
B <sub>3</sub>	27.92 (±0.51) d	39.60 (±0.33) c	64.12 (±0.68) d	35.44 (±0.24) d
B <sub>4</sub>	30.67 (±0.33) c	45.82 (±0.48) b	69.40 (±0.40) c	42.17 (±0.10) c
B <sub>5</sub>	36.33 (±0.33) a	52.30 (±0.71) a	77.23 (±0.62) a	51.46 (±0.70) a
B <sub>6</sub>	33.75 (±0.25) b	50.04 (±0.11) a	74.37 (±0.32) b	48.39 (±0.66) b
Level of significance $P$ (5%)				
B	<0.001	<0.001	<0.001	<0.001

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm.  $P$  = probability. Means were separated by Tukey's test at  $P \leq .05$ .



**Figure 5.** Response of SCMR values to (A) number of pegs plant<sup>-1</sup>, (B) number of pods plant<sup>-1</sup>, (C) 100 seeds weight and (D) pods dry weight plant<sup>-1</sup>.

Notes: Dots represent the values of the studied parameter for the treatments ( $B_1 = 0$  ppm,  $B_2 = 0.5$  ppm,  $B_3 = 1$  ppm,  $B_4 = 2$  ppm,  $B_5 = 4$  ppm,  $B_6 = 8$  ppm.). Dotted line represents the best linear fit to the values of studied parameters. Means were separated by Tukey's test at  $P \leq .05$ .

### Correlation of stomatal number and reproductive development

There was a linear response of stomatal number to reproductive development of peanut (Figure 6). When stomatal number was 35.73 (abaxial surface) and 35.87 (adaxial surface) the reproductive development was higher at those points. The leaf stoma is a pivotal gate controlling the exchange of CO<sub>2</sub> and water vapor, although such processes may be affected by many environmental variables, including light, water status, temperature, and CO<sub>2</sub> concentration [28]. The CO<sub>2</sub> is the photosynthetic substrate in the intercellular space, and its concentration can be calculated from water diffusion through the leaf, showing a coupling interaction between CO<sub>2</sub> entry for photosynthesis and water vapor emitted via transpiration (Boyer et al. 1997). Therefore, stomata numbers directly correlate to the production of higher reproductive units.

### Peg strength and shelling (%)

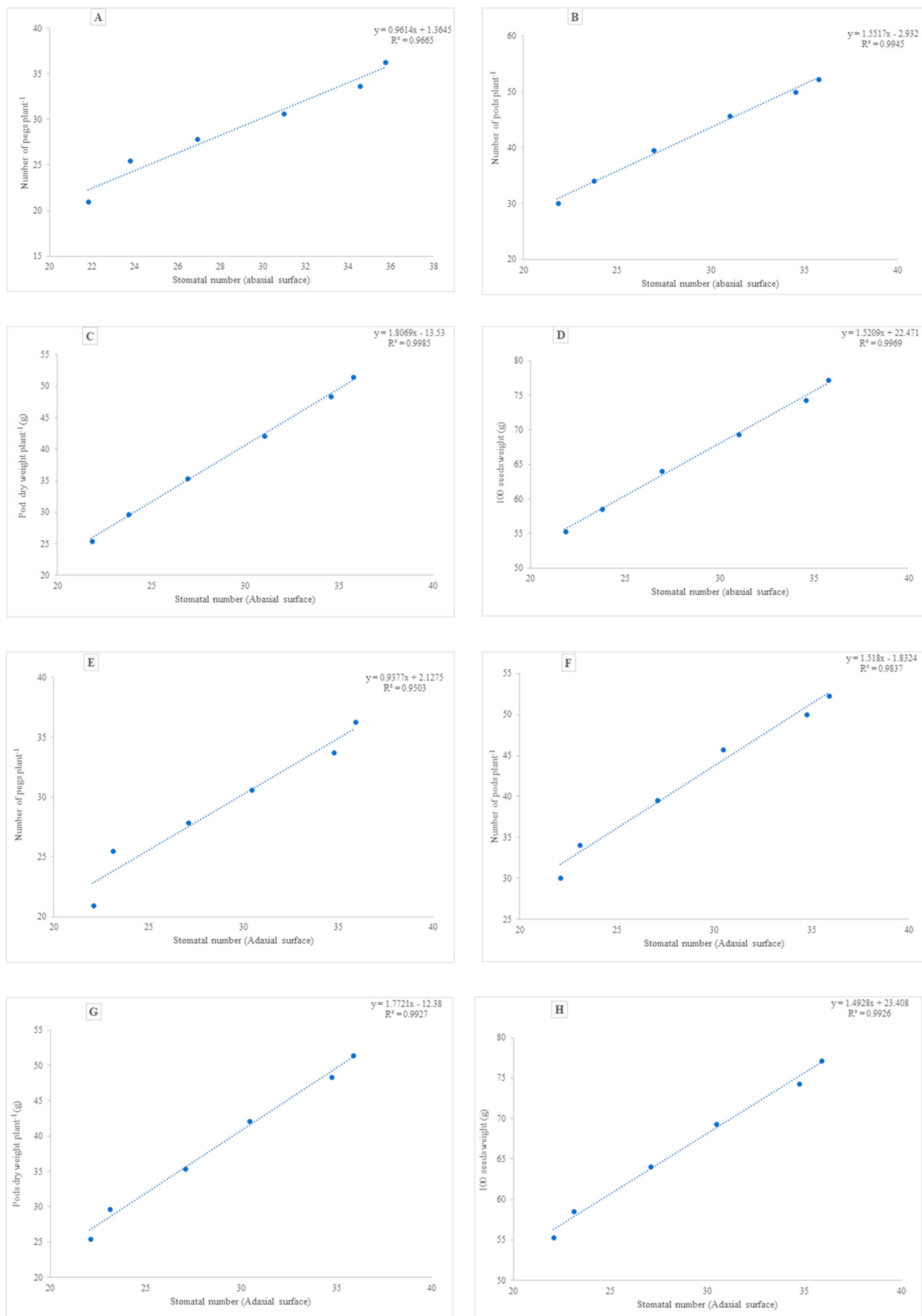
Pod strength and shelling percentage were recorded with significantly ( $P < .05$ ) important influence from the different levels of boron (Figure 7). Pod strength ranged from 2.55 newtons to 7.24 newtons and shelling (%) ranged from 61.83% to 74.59%. Results indicated that the highest value of peg strength and shelling (%) was obtained most from

the  $B_5$  treatment than the other treatments. This may have been caused by the boron involvement in cell development as well as sclerenchyma tissue development (Naiknaware et al. 2015) of pegs and pods. Kabir et al. (2013) stated that boron was responsible for producing the healthier pods in peanut.

The result indicated that along with the increase in boron concentration (>4 ppm), vegetative growth, leaf gas exchange, reproductive development, physiological and nutritional changes, peg strength and shelling (%) were decreased.

### Nutritional change

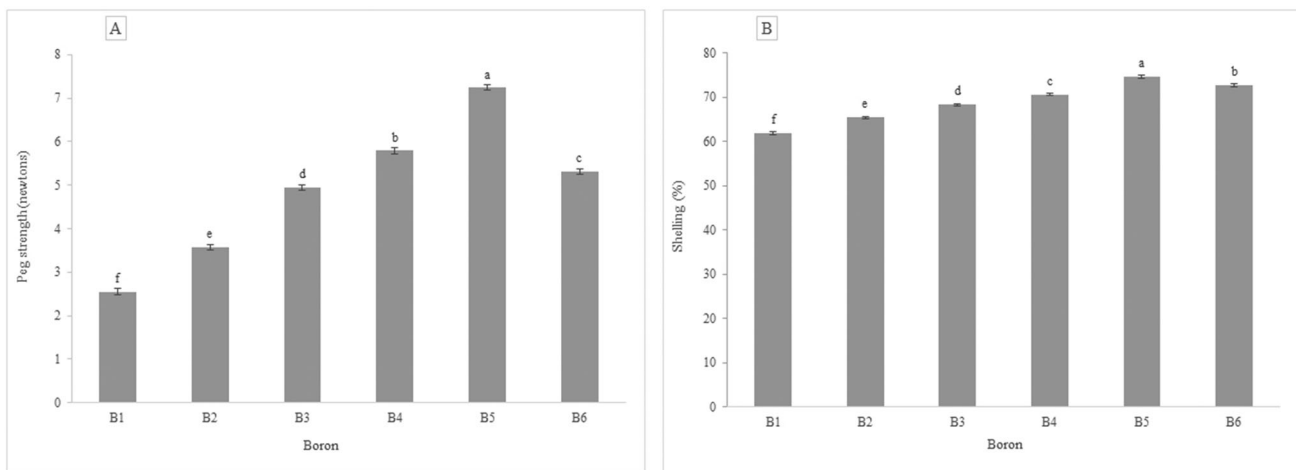
Mineral elements obtained for varying boron levels were significantly higher (Table 5). The treatment  $B_6$  produced the highest value of sodium, potassium, calcium, magnesium, iron, zinc; and the lowest levels for  $B_0$ . This may be because the appropriate supply of boron was containing the required nutrient to produce the higher mineral elements. Boron played an important role in the synthesis of essential amino acids, and protein that acts as an electron carrier in the photosynthetic process (Naiknaware et al. 2015) which is required for producing of mineral elements. All of others studied parameters showed highest values for treatment  $B_5$ , but for mineral elements it showed highest for treatment  $B_6$ . This might be due to the excess supply of boron having caused toxic effects on the plants and plants were suffering in a stress



**Figure 6.** Response of abaxial stomatal numbers to (A) number of pegs plant<sup>-1</sup>, (B) number of pods plant<sup>-1</sup>, (C) 100 seeds weight, (D) pods dry weight plant<sup>-1</sup>, and adaxial stomatal number to (E) number of pegs plant<sup>-1</sup>, (F) number of pods plant<sup>-1</sup>, (G) 100 seeds weight and (H) pods dry weight plant<sup>-1</sup>.

Notes: Dots represent the values of the studies parameter for the treatments ( $B_1 = 0$  ppm,  $B_2 = 0.5$  ppm,  $B_3 = 1$  ppm,  $B_4 = 2$  ppm,  $B_5 = 4$  ppm,  $B_6 = 8$  ppm). Dotted line represents the best linear fit to the values of studied parameters. Means were separated by Tukey's test at  $P \leq .05$ .





**Figure 7.** Effect of boron on peg strength (A) and shelling (%) (B) of peanut.

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm. Means were separated by Tukey's test at  $P \leq .05$ . Vertical bars represent the SE of the treatment means.

**Table 5.** Effect of boron on nutritional changes of peanut (mg/100 g).

Treatment	Sodium	Potassium	Calcium	Magnesium	Iron	Zinc
Boron						
B <sub>1</sub>	24.00 ( $\pm 0.58$ ) e	1254.67 ( $\pm 2.60$ ) e	76.00 ( $\pm 1.00$ ) f	354.00 ( $\pm 2.65$ ) e	1.91 ( $\pm 0.02$ ) f	3.10 ( $\pm 0.03$ ) f
B <sub>2</sub>	28.00 ( $\pm 0.58$ ) d	1291.67 ( $\pm 2.03$ ) d	82.33 ( $\pm 0.88$ ) e	367.67 ( $\pm 1.45$ ) d	2.05 ( $\pm 0.09$ ) e	3.80 ( $\pm 0.03$ ) e
B <sub>3</sub>	31.00 ( $\pm 0.58$ ) d	1308.66 ( $\pm 1.86$ ) c	94.00 ( $\pm 1.16$ ) d	375.67 ( $\pm 2.90$ ) d	2.21 ( $\pm 0.09$ ) d	4.52 ( $\pm 0.04$ ) d
B <sub>4</sub>	39.67 ( $\pm 0.88$ ) c	1620.33 ( $\pm 0.88$ ) b	117.33 ( $\pm 0.88$ ) c	437.67 ( $\pm 1.45$ ) c	2.98 ( $\pm 0.006$ ) c	5.12 ( $\pm 0.02$ ) c
B <sub>5</sub>	43.00 ( $\pm 0.58$ ) b	1627.33 ( $\pm 1.20$ ) b	126.33 ( $\pm 0.88$ ) b	447.00 ( $\pm 1.16$ ) b	3.16 ( $\pm 0.09$ ) b	6.06 ( $\pm 0.04$ ) b
B <sub>6</sub>	48.00 ( $\pm 0.58$ ) a	1691.00 ( $\pm 0.95$ ) a	134.00 ( $\pm 1.16$ ) a	457.00 ( $\pm 1.20$ ) a	3.77 ( $\pm 0.02$ ) a	6.97 ( $\pm 0.01$ ) a
Level of significance $P$ (5%)						
B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Notes: B<sub>1</sub>= 0 ppm, B<sub>2</sub>= 0.5 ppm, B<sub>3</sub>= 1 ppm, B<sub>4</sub>= 2 ppm, B<sub>5</sub>= 4 ppm, B<sub>6</sub>= 8 ppm.  $P$  = probability. Means were separated by Tukey's test at  $P \leq .05$ .

condition. There is evidence that during stress conditions, plants make defense mechanism within itself (Sharma et al. 2012) while producing anti-oxidants as well as high levels of mineral elements. This finding is consistent with the findings of Quamruzzaman et al. (2016b).

The results indicate that with increasing the boron concentration (up to 8 ppm), the protein, oil and vitamin E content will increase as well. In order to validate this increasing trend, further research should be conducted.

## Conclusion

In conclusion, the values obtained for all vegetative and physiological growth parameters, leaf gas exchange, net photosynthetic rate, reproductive development, peg strength and shelling (%) for treatment B<sub>5</sub> were higher than those obtained for all other treatments. Further, the values obtained for nutritional traits were highest in B<sub>6</sub> than in the other treatments. Thus, B<sub>5</sub> can be used to culture peanut as it provides higher growth, development and yield, on the other hand B<sub>6</sub> can be used to obtain higher nutrient content.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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