



***Review Paper***

**BORON DEFICIENCY AND TOXICITY AND THEIR TOLERANCE IN PLANTS: A REVIEW**

**Archana, N. Pandey and Preetam Verma<sup>1</sup>**

Department of Botany,  
Plant Nutrition and Stress Physiology Laboratory,  
University of Lucknow, Lucknow-2006007, India.

<sup>1</sup>Department of Molecular and Cellular Engg,  
JSBB, SHIATS, Allahabad.211007,  
India.

**Abstract**

Boron is an essential micronutrient for higher plants. Although its requirement in plants is very low, it has been assigned important roles in many metabolic processes. The deficiencies as well as toxicities of boron occur in a wider range of crops and climatic conditions than deficiencies of any other micronutrient element and have adverse effect on growth and development of plants. Both vegetative as well as reproductive growth of the plant was known to be adversely affected by the boron stress. Foliar and soil fertilization is the option for the soil boron deficiency treatment but for toxicity, tolerant plants are most appropriate option. Hence, in the present article, information on boron deficiency, its toxicity and the tolerance shown by plants has been reviewed.

Key words: Boron; deficiency; toxicity; tolerance.

**INTRODUCTION**

Boron deficiency is the most widespread micronutrient deficiency in agricultural crops in world including India. The symptoms of boron deficiency are observed when boron content in soil comes down to 5 to 25 mg ha<sup>-1</sup>. Aluminium hydroxide adsorbs large amounts of soluble boron, making the soil acidic and causing boron deficiency. Soils containing a high proportion of organic matter are less deficient in boron.

Boron-rich soils are of great significance because of their association with boron toxicity and decreased plant growth and crop yields in different regions, especially arid and semi-arid regions of the world. The highest naturally occurring concentration of boron have been found in soils derived from marine evaporates and marine argillaceous sediments [1]. In addition, various anthropogenic sources of boron excesses may increase soil boron to toxic levels for plants. The most important source is irrigation waters, but other sources such as wastes from surface mining, fly ash industrial chemicals, municipal composts, sewage sludges, and effluents from agricultural land may also play a role in boron toxicity. The poor drainage of saline soils may be responsible for the excessive accumulation of boron in the soil solution [2].

## BORON DEFICIENCY AND SYMPTOMS

Boron deficient soils are distributed globally. Boron deficiency is the most widespread of all the micronutrient deficiencies in many crop regions from tropical to temperate zones. Deficiency is most prevalent on coarse-textured (sandy) soils of the humid regions, where high leaching losses of boron (eg. Podzols, podzols) further deplete the inherently low boron content of soils to deficiency levels. Soil analysis reveals boron deficiency to be common in Nepal, Phillipines, India and Thailand [3].

Some characteristic boron deficiency symptoms in plants are: 'Top sickness' of tobacco; 'Corky core' or 'internal cork' or 'drought spot' of apple; 'Water core' of turnip; 'Hard fruit' of Citrus; 'Yellows' of alfa alfa; 'Hen and chicken' of grapes; 'Heart rot' of sugarbeet; 'Stem crack' of celery; 'Hollow stem' of cauliflower and broccoli; 'Brown heart' of swade and 'Tipburn' of chinese cabbage [4,5,6].

Generally, symptoms of boron deficiency appear first in terminal shoots in the form of small, deformed leaves, borne on severely condensed branches. The growth of apical meristems is arrested and the shoot apex turns necrotic, giving rise to multiple axillary branches, which eventually turn necrotic. This gives the B deficient plants a bushy appearance. Stem of boron deficient plants also turn brittle and show longitudinal splits of the cortex. The petiole and stem of boron deficient plants show longitudinal and transverse splits or corky ridges [6].

Sunflower is one of the most sensitive crops to low boron supply, developing characteristic boron deficiency symptoms on leaves, stems and reproductive parts [7,8]. These deficiency symptoms first become evident on the younger leaves, which develop a bronze colour and become hardened, malformed and necrotic, the stem becomes corky, the capitulum deformed and poor seed set results [7]. Sunflower roots are also sensitive to boron deficiency as they stop their growth in less than 6 h after the removal of boron from the growth medium [9].

In pea, boron deficiency results in the formation of a weak root system, bud abortion on the top and leaf hardening [10]. In boron deficient onion plants [11] leaves were thick, brittle and blue green in color and had hard and rough surface scales associated with necrosis of the inner scales. Under moderate deficiency, the outer leaves of the onion head appeared thick and brittle. Cauliflower also showed somewhat similar symptoms under moderate deficiency of boron on these plants. The outer leaves appeared thick and brittle and the leaf petiole and midribs developed small blisters and cracks [12]. A conspicuous feature of boron deficient leaves of cabbage and cauliflower is a thick layer of epicuticular wax that gives the leaves a bluish appearance. In lettuce, margins of young leaves become scorched and ragged, appear 'hooked' and distorted.

In higher plants, the most rapid response to boron depletion or deficiency is the inhibition or cessation of root elongation in both the main and lateral roots and this has been described by many workers [9,13]. Inhibition of root tip elongation was reported within hours after removal of boron from nutrient solution [14]. It has been demonstrated that the inhibition of root elongation caused by boron deficiency can be corrected if boron is re-supplied before the meristematic region of the root tips is permanently damaged [15]. They observed that the root tip elongation of boron deficient squash plant (*Cucurbita pepo*) slowed down after 3 h, was severely inhibited within 6h and completely stopped after 24 h of supply of deficient boron treatment in the nutrient solution. If boron was resupplied after 12 hr, the rate of root elongation was restored to normal within 12-18 hrs. Inhibition of root elongation in tomato (*Lycopersicum esculentum*) was also observed within 3h after withdrawal of boron from the nutrient solution [9].

Singh, [16] observed that boron increased nodulation in the roots of dhaincha (*Sesbania cannabina*). In root crop such as turnip, raddish and sugarbeet (*Beta vulgaris*) and carrot (*Daucus carota*) discoloration, browning and curling of young terminal leaves (crown) form early symptoms of boron deficiency [17]. As deficiency persists the root surface develops wrinkles and cracks and softer tissue of core develops water soaked areas resulting in tissue disintegration. Shelp and Shattuck [18] reported external roughness and brown necrosis in roots of rutabaga and wilkelmsberger plants under severe boron deficiency. Boron deficient plants also develop numerous lateral roots and adventitious roots with enlarged and necrotic tips in sunflower [19].

Flowering and fruit formation is adversely affected by boron deprivation. The flowers formed in boron deficient cotton [20] and *Zinnia elegans* [21] were abnormal. In most fruit trees, boron deficiency leads to shortening of internodes. Under severe deficiency, the terminal shoots may 'die -back' and the terminal buds remain rudimentary. Stems show splitting of bark, fruits have rough surface, develop cracks and are often malformed.

Premature fruit dropping was reported in boron deficient peach [22]. Parthenocarpic development of fruits due to abortion of embryosac has been reported under boron deficiency in *Cola nitida* [23]. Development of corky spots followed by fruit drop was reported in apples and grapes by Zachos et al., [24]. Fruits of boron deficient plants became malformed in papaya and grapes [25, 26].

Some of the effects of boron deficiency in maize were appearance of white translucent streaks in the middle of the leaf lamina, reduced leaf area, failure of young emerging leaf to unroll, short and thick internodes and cessation of apical growth. The deficiency symptoms of boron observed in periwinkle include reduction in growth, leaf area and chlorosis thickening and curling of leaves, terminal chlorosis, downward cupping of young emerging leaves, shortening of internodes, and death of growing tips of stem [27].

### **BORON DEFICIENCY TOLERANCE IN PLANTS**

Several crop genotypes are known to show genotypic differences in boron efficiency [28,29]. Based on differences in seed yield on low boron soils of Chiang Mai (Thailand), Rerkasem and Jamjod, [28] have reported genotypic differences in boron efficiency in wheat, barley, green gram, black gram and soybean. Wheat cultivars SW 41 and Fang 60 showed marked difference in boron efficiency. The boron inefficient wheat cultivar SW 41 showed even higher sensitivity to boron deficiency than the dicotyledonous cultivars. Wheat has otherwise been rated as highly tolerant to boron deficiency [30]. Rerkasem and Jamjod, [29] have suggested that advanced lines of wheat genotypes, found to be boron efficient on the basis of performance (yield) on low boron soils, should be used for development of boron efficient varieties. This has advantage over the use of the international wheat germplasm available with the international Center for Maize and Wheat Research (CIMMYT) in breeding for tolerance to boron deficiency as the latter is reported to be largely boron inefficient [29].

### **BORON TOXICITY AND SYMPTOMS**

Boron toxicity is a worldwide problem that significantly limits crop yield in agricultural areas of Australia, North Africa, and West Asia and is characterized by alkaline and saline soils together with a low rainfall and very scarce leaching. In addition, B-rich soils also occur as a consequence of over fertilization and/or irrigation with water containing high levels of B [31].

The symptoms on roots were similar to moderate boron deficiency symptoms and exhibited a water soaked appearance of the tissues in the center of the root [32]. In peach boron toxicity caused distortion of leaf, shoot die back, and leaf bud mortality after dormancy, increased break of lateral shoot and flower buds, reduced pollen viability and fruit set [33]. In barley, toxicity of the boron is characterized by elongated, dark-brown blotches at the tips of the older leaves followed by browning and burning of older leaf tips. In oats toxicity of B results in light yellow bleached leaf tips [34].

Boron tends to accumulate in the leaf margins of the dicotyledons and leaf tips of monocotyledons and therefore most boron toxicity effects are known to first appear in these regions. The B toxicity symptoms are generally similar for most plants and appear in the leaves as marginal or tip chlorosis, which is followed by necrosis. Besides marginal chlorosis, the leaves in rutabaga had a tendency to curl and wrinkle. Boron toxicity in turnip seedlings also results in marginal bleaching of the cotyledons and first leaves [35].

In pea, Gupta and Macleod, [36] showed that boron toxicity results in burning of the edges of the old leaves. The extent of burning of upper leaves depends on the degree of boron toxicity. In radish boron excess is characterized by marginal yellowing and burning of lower leaves. In red clover (*Trifolium pratense* L.) toxicity symptoms of boron include burning and yellowing of the older leaf edges [37]. In straw berries (*Fragaria xananassa* Duch.) slight boron toxicity was associated with marginal curling and interveinal bronzing and necrotic lesions; under severe boron toxicity interveinal necrosis was severe, leaf margins became severely distorted and cracked, and overall plant growth was reduced [38].

High doses of boron (1-10 ppm) caused yellowing and enhanced plant growth in tomato [39] but reduced the fruit quality. Lovatt and Bates, [40] observed boron accumulation, inhibition of fruit elongation and lateral root development in boron toxicity in cucumber. In cow pea (*Vigna unguiculata* L. Walp) moderate boron toxicity results in marginal chlorosis and spotted necrosis but under severe boron toxicity, trifoliate leaves show slight marginal chlorosis [41]. Boron toxicity in snap bean (*Phaseolus vulgaris* L) results in the marginal chlorosis of the older trifoliate leaves while unifoliate leaves were chlorotic with intermittent marginal necrosis [41].

In pepper, toxicity symptoms first appeared on the oldest leaves and spread to the younger leaves. The margins became broader, developed necrotic blotches, turned faded brown and younger leaves remained small. In tomato plants, brown and necrotic lesions appeared in leaflet tips, which curled inwards [1]. Leaves show tip and marginal burning and yellowing between the veins in maize and apical and marginal chlorosis in older leaves in periwinkle plants toxic in boron [27].

## **BORON TOXICITY TOLERANCE IN PLANTS**

Remediation of boron-toxic soils is impractical in most cases so solutions based on improved plant tolerance to boron have been investigated for several decades by plant breeders and more recently biotechnologists. Plant tolerance to boron toxicity has been identified in a range of genotypes and recent research has revealed a physiological mechanism behind this tolerance in cereals. Cultivars with high levels of expression of a gene encoding a boron-efflux transporter in roots and shoots have been reported to show tolerance to high boron in soils. It was proposed that the higher expression of the gene Bot1, a BOR1 ortholog, in a tolerant barley cultivar was due to amplification of the boron transporter gene [42]. Overexpression of gene AtBOR4 in Arabidopsis of a boron-efflux transporter BOR4 in roots was shown to enhance tolerance [43]. Originally,

tolerance conferred by the boron-efflux transporter gene was attributed only to reduced root accumulation. An additional mechanism involving redistribution of boron from the symplast into the apoplast in leaves by the same efflux transporters, enhanced tolerance [44]. Boron-tolerant varieties are characterized by a decreased B concentration in their leaf tissues in comparison with nontolerant varieties, probably due to a reduced uptake of B into both roots and shoots. In this sense, the basis for B-tolerance in the landrace barley cultivar Sahara has been explained by its high ability to efflux B, and two models have been reported for this mechanism of active efflux of B, namely, anion (borate) exchange or an anion channel [45]. It has been suggested that the BOR2 gene encodes an efflux type borate transporter responsible for tolerance to B toxicity in wheat and barley [31]. Bogacki et al., [46] reported that gene MtNIP3, in *M. truncatula* is associated with B toxicity tolerance. They also suggested that the MtNIP3 provides a source of molecular selection tools to maintain the tolerance trait in Medicago breeding programs.

## CONCLUSION

Boron is neither constituent of any enzyme nor does it directly affect any enzyme activity, but it has an important role in- sugar transport, cell wall synthesis, lignification of cell wall structure, membrane integrity, carbohydrate metabolism, RNA metabolism, IAA and phenol metabolisms [47]. Boron is also probably more important than any other micronutrients for high quality crop yields. Tolerant varieties are one of the main approaches of obtaining enhanced crops in boron stressed soils.

## REFERENCES

- [1] Eraslan F., Inal A., Gunes A., Alpaslan M., 2007., Boron toxicity alters nitrate reductase activity, proline accumulation, membrane permeability and mineral constituents of tomato and pepper plants. *Journal of Plant Nutrition*, 30, 981-994.
- [2] Grieve, C. M., and Poss, J.A., 2000, Wheat response to interactive effects of boron and salinity. *Journal of Plant Nutrition*, 23, 1217-1226.
- [3] Sillanpaa, M., 1982, Micronutrients and the nutrient status of soils. A global study. *Soils Bulletin No. 48*. FAO, Rome.
- [4] Wallace, T., 1961, *The Diagnosis of Mineral Deficiencies in Plants. A Color Atlas and Guide*, HMSO, London.
- [5] Gupta, U. C. and Cutcliffe J. A., 1973, Boron nutrition of broccoli, 4962russels sprouts and cauliflower grown on Prince Edward Island Soils. *Canadian Journal of Soil Science*, 53, 275-279.
- [6] Kuo, C. G., Tsay, J. S., Tsai, C. L. and Chen, R. J., 1981, Tip burn of Chinese cabbage in relation to calcium nutrition and distribution. *Scientia. Horticulturae (Amsterdam)*, 14, 131-138.
- [7] Blamey, F. P. C., Edwards, D. G. and Asher, C. J., 1987, Nutritional disorders of sunflower. St. Lucia, Australia, Department of Agriculture, University of Queensland.
- [8] Asad, A., 2002, Boron requirements of sunflower and wheat. *Journal of Plant Nutrition*, 25, 885-899.
- [9] Dugger, W. M., 1983., Boron in plant metabolism. In: *Encyclopedia of Plant Physiology*, New Ser. 15 B Inorg. Pl. Nutr. Pt. B. pp. 626-650.
- [10] Li, C., Dannel, F., Pfeffer, H., Römheld, V., and Bangerth, F., 2001, Effect of boron starvation on boron compartmentation, and possibly hormone-mediated



- elongation growth and apical dominance in pea (*Pisum sativum*) plants. *Physiologia Plantarum*, 111, 212-219.
- [11] Calbo, N. E. R., Monnerat, P. H. and Shimoya, C, 1986a., The characterization of boron deficient symptoms in onion (*Allium cepa* L.) during production stage. *Revista Ceres*, 33, 274-280.
- [12] Hewitt, E. J., 1983, The essential and functional mineral elements. In "Diagnosis of Mineral Disorders in Plants". Vol. I. Principles (J. B. D. Robinson, ed.) H. N. S. O. London. Pp, 7-53.
- [13] Marschner, H., 1995, Mineral Nutrition of Higher Plants. 2<sup>nd</sup> Ed. Academic Press, San Diego, U. S. A. pp, 379-396.
- [14] Hirsch, A. M. and Torrey, J. G., 1980, Ultrastructural changes in sunflower root cells in relation to boron deficiency and added auxin. *Canadian Journal of Botany*, 58, 856-866.
- [15] Bohnsack, C. W., and Albert, L. S., 1977, Early effects of boron deficiency on indoleacetic acid oxidase levels of squash root tips. *Plant Physiology*, 59, 1047-1050.
- [16] Singh, R. G., 1972, Effect of phosphate and boron on growth, nodulation and seed yield of dhaincha *Sesbania cannabina*. *Retz. Pers. Indian Journal of Agricultural Sciences*, 42, 139-144.
- [17] Gupta, U. C. and Cutcliffe, J. A., 1985, Boron nutrition of carrots and table beets grown in a boron deficient soil. *Communications in Soil Science and Plant Analysis*, 16, 509-516.
- [18] Shelp, B. J. and Shattuck, V. I., 1987, Boron nutrition and mobility and its relation to elemental composition of green house grown root crops. I Rutabaga. *Communications in Soil Science and Plant Analysis*, 18, 187-201.
- [19] Josten P. and Kutschera, U., 1999, The micronutrient boron causes the development of adventitious roots in sunflower cuttings. *Annals of Botany*, 84, 337-342.
- [20] De Silva, N. M., Carvalho, L. H., Bataglia, O. C. and Hiroce, R., 1979, Effect of boron on cotton cultivated under greenhouse conditions. *Bragantia* 38, 153-164.
- [21] Redington, C. B. and Peterson, J. L., 1983, Influence of boron on bud blasting and plant growth in *Zinnia elegans*. *Bulletin of the Torrey Botanical Club*, 110, 77-79.
- [22] Kim, K. R., Byun, J. R. and Kim, C. C., 1970, Studies on boron deficiency in a peach orchard. *Research Report of the Office of Rural Development*, 12, 29-34.
- [23] Jacob, V. J., Engbe, N. E. and Okoloko, G. E., 1972, Abnormalities in vegetative and floral organs of *Cola nitida* caused by boron deficiency. *Canadian Journal of Botany*, 50, 381-383.
- [24] Zachos, D.G., Gavalas, N.A. and Holevas, C.D., 1973, Corky spots in grapes, a symptom of boron deficiency. *Annales de l'Institut Phytopathologique Benaki*, 10, 354-356.
- [25] Wang, D. and Ko, W. H., 1975, Relationship between deformed fruit disease of papaya and boron deficiency. *Phytopathology*, 65, 445-447.
- [26] Kuniyuki, H., Terra, M. M., Hiroce, R. and Costa, A. S., 1985, Chocolate browning of berries and leaf chlorosis: a grapevine disorder caused by boron deficiency. *Bragantia*. 44, 187-196.

- [27] Pandey, N. and Archana, 2009, Boron-stress induced changes in water status and stomatal morphology in *Zea mays* L. and *Catharanthus roseus* L. Indian Journal of Plant Physiology, 14(3), 310-314.
- [28] Rerkasem, B. and Jamjod, S., 1997, Genotypic variation in plant response to low boron and implications for plant breeding. Plant and Soil, 193, 169-180.
- [29] Rerkasem, B. and Jamjod, S., 2004, Boron deficiency in wheat: a review. Field Crops Research, 89, 173-186.
- [30] Martens, D. C. and Westermann, D. T., 1991, Fertilizer application for correcting micronutrient deficiencies. In: *Micronutrients in Agriculture* 2<sup>nd</sup> ed. (J. J. Mortvedt, F. R. Cox, L. M. Schuman, R. M. Welch, (eds) *Soil Science Society of America*, Book Series Madison WI. Pp, 549-592.
- [31] Reid R., 2010, Can we really increase yields by making crop plants tolerant to boron toxicity? Plant Science, 178, 9-11.
- [32] Gupta, U. C. and Munro, D. C., 1969, The boron content of tissues and roots of rutabagas and of soil as associated with brown heart condition. Soil Science Society of America, Proceedings, 33, 424.
- [33] Kamali, A. R. and Childers N. F., 1970, Growth and fruiting of peach in sand culture as affected by boron and fritted form of trace elements. Journal of the American Society for Horticultural Science, 95, 652-656.
- [34] Gupta, U. C., 1971, Boron 4964russels4964nt of alfalfa, red clover, 4964russels sprouts and cauliflower grown under greenhouse conditions. Soil Science, 112, 280-281.
- [35] Muller, F. B. and Mc Sweeney, G., 1976, Toxicity of borates to turnips. New Zealand *Journal of Experimental Agriculture*, 4, 451-455.
- [36] Gupta, U. C. and McCleod, J. A., 1981, Plant and Soil B as influenced by soil pH and calcium sources on podzol soils, Soil Science, 131, 20-24.
- [37] Gupta, U. C., 1984, Boron nutrition of alfalfa (*Medicago sativa*), red clover (*Trifolium pretense*) and timothy (*Phleum partense*) grown on podzol soil of eastern Canada. Soil Science, 1, 16-22.
- [38] Haydon, G. F., 1981, Boron toxicity of strawberry. Communications in Soil Science and Plant Analysis, 12, 1085.
- [39] Alvarez- Tinaut, M. C., Leal, A. and Recalde, L., 1981, Physiological effect of B-Mn interaction in tomato plants. *Agrokhimica*, 25, 501-514.
- [40] Lovatt, C. J. and Bates, L. M., 1984, Early effects of excess boron on photosynthesis and growth of *Cucurbita pepo*. Journal of Experimental Botany, 33, 297-305.
- [41] Francois, L. E., 1989., Boron tolerance of snap bean and cow pea. Journal of the American Society for Horticultural Science, 114, 615.
- [42] Sutton, T., Baumann, U., Hayes, J., Collins, N. C., Shi, B. J., Schnurbusch, T. et al., 2007, Boron-toxicity tolerance on barley arising from efflux transporter amplification. *Science* 318, 1446-1449.
- [43] Miwa, K., Takano, J., Omori, H., Seki, M., Shinozaki, K. and Fujiwara, T., 2007, Plants tolerant of high boron levels. *Science*, 318, 1417.
- [44] Reid, R. and Fitzpatrick, K., 2009, Influence of leaf tolerance mechanisms and rain on boron toxicity in barley and wheat. *Plant Physiology*, 151, 413-420.
- [45] Hayes, J. E., Reid, R. J., 2004, Boron tolerance in barley is mediated by efflux of boron from the roots. *Plant Physiology*, 136, 3376-3382.

- [46] Bogacki, P., Peck, D. M., Nair, R. M., Howie, J. and Oldach, K. H., 2013, Genetic analysis of tolerance to Boron toxicity in the legume *Medicago truncatula* BMC Plant Biology, 13, 54
- [47] Dordas, C. and Brown, P. H., 2000, Permeability of boric acid across lipid bilayers and factors affecting it. Journal of Membrane Biology, 175, 95-105.