Boron transport in plants: coordinated regulation of transporters

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Boron (B) is essential for plants

B deficiency symptoms

Cross-linking of RG-II in cell wall

Occurrence of B deficiency was reported in 80 countries and 132 crop species (Shorrocks, 1997)
High concentration of B is toxic.

Plants need to control B concentration in optimum range.

(Watanabe, 1985)

Presentation by Sakamoto, 30th, 3:00pm
Boron transporters?

\[ \cdot B(OH)_3 + H_2O \rightarrow B(OH)_4^- + H^+ \]

( \( pK_a = 9.25, \ 25 ^\circ C \) )

Boron is transported passively along transpiration stream.

Fig. 2.22  Schematic presentation of uptake rates of potassium, sodium, and boron in barley roots with increasing supply of KCl + NaCl and boron. Uptake rates of other mineral elements in brackets.

(Marschner 1995)
B homeostasis by regulation of B transporters

- **Low B**
  - Preferential distribution of B into young portions by **NIP6;1**

- **High B**
  - Exclusion of toxic B by **BOR4**

(1) Efficient uptake and xylem loading of B by **NIP5;1** and **BOR1**
Arabidopsis thaliana bor1-1 is defective in xylem loading of boron.

(Noguchi et al., 1997, Takano et al., 2002 Nature)
BOR1 concentrates B into xylem under low B supply. (Xylem loading) (Takano et al., 2002, Nature)
BOR1 accumulation is regulated at post-transcriptional level.

(Takano et al., 2005, PNAS)
B transport model by BOR1

High B

Epidermis  Cortex  Endodermis

Casparian strip

Low B

Xylem-directed export of B by BOR1

BOR1
**NIP5;1** is upregulated by low B

*NIP5;1* mRNA level in roots

(Takano et al. 2006 Plant Cell)
NIP5;1 is important for efficient B uptake in roots under low B.

(Takano et al. Plant Cell 2006)
B transport model in Arabidopsis

**High B**

- Media
- Epidermis
- Cortex
- Endodermis
- Pericycle
- Xylem parenchyma
- Casparian strip

**Low B**

- NIP 5;1
- BOR1

**Transcriptional regulation**

**post-transcriptional regulation**
Coordinated expression of transporters and channels

Channels facilitate influx into cells

Transporters export out of the cells against concentration gradient
NIP6;1 preferentially distributes B into young leaves under limited B.

(Tanaka et al. 2008 Plant Cell)
A Rice BOR1 ortholog also functions in B transport

OsBOR1 (XII) 3830 bp (2137 bp)

osbor1-1  osbor1-2

WT 10 cm -B

osbor1

(Nakagawa et al., 2007 Plant Cell)
Presence of efflux B transporter for B tolerance was predicted in barley. (Hayes et al., 2004)
Which is for B tolerance among six BORs in Arabidopsis?

**Required for growth under B limitation**

**Specifically expressed in pollen**
BOR4-GFP was not decreased upon high B supply.

(Miwa et al., 2007 Science)
B concentrations were decreased in BOR4 expressing lines.

(Boron concentrations were decreased in BOR4 expressing lines.)

++ B (3 mM)

(Boron concentrations were decreased in BOR4 expressing lines.)

(Miwa et al., 2007)
BOR4 is localized to distal side of plasma membrane of root epidermis.

(Miya et al., 2007)
Overexpression of BOR1 improved plant growth under B limitation

(Miwa et al., 2006, Plant J)
Enhanced expression of *NIP5;1* improved root growth

Wild type  NIP5;1AC/35S-BOR1  35S-BOR1  NIP5;1AC/35S-BOR1

Grown on -B media for 23 days

Bar : 5 cm

(Kato et al., 2009)
Overexpression of BOR4 conferred high B tolerance.

Wild type | BOR4 overexpressing Arabidopsis

++B
Toxic level B
10 mM

(Miwa et al., 2007, Science)
B homeostasis by regulation of B transporters

(1) Efficient uptake and xylem loading of B by NIP5;1 and BOR1

(2) Preferential distribution of B into young portions by NIP6;1

(3) Exclusion of toxic B by BOR4
Conclusion

• Plants regulate B transport.
• Expressions of B transporters are regulated at mRNA and protein levels in response to B conditions.
• Polar localization of the transporters is likely to be important for directional trans-cellular transport.
• B transporters are useful for improvement of B-stress tolerance.