

# A significant *P* value: How phosphorus controls plant height

Kutubuddin A. Molla <sup>1,2</sup>

- 1 Assistant Features Editor, The Plant Cell, American Society of Plant Biologists
- 2 ICAR-National Rice Research Institute, Cuttack 753006, India

## In Brief

Phosphorus plays key roles in photosynthesis, respiration, development, reproduction, and the biosynthesis of membranes and nucleic acids (Lambers 2022). Modern agriculture is highly dependent on inorganic phosphorus (Pi). Soil Pi deficiency induces a series of physiological changes and can affect plant architecture, including plant height. However, the molecular mechanism governing Pi-regulated plant height remains largely unknown. Taller rice plants tend to fall over in strong winds and heavy rains, a phenomenon known as lodging. Amid climate change and more extreme weather events, such as cyclones, typhoons, and heavy rains, crop lodging often leads to yield loss. Plant height is intricately linked with resistance to lodging and yield. During the Green Revolution, the improvement in yield for rice and wheat was attributed to changes in plant architecture, specifically a reduction in plant height linked to lodging resistance. Although semi-dwarf rice varieties have played a significant role in feeding the world over the last 50 years, shallow lowland and semi-deep ecologies demand rice varieties with tall heights and lodging resistance.

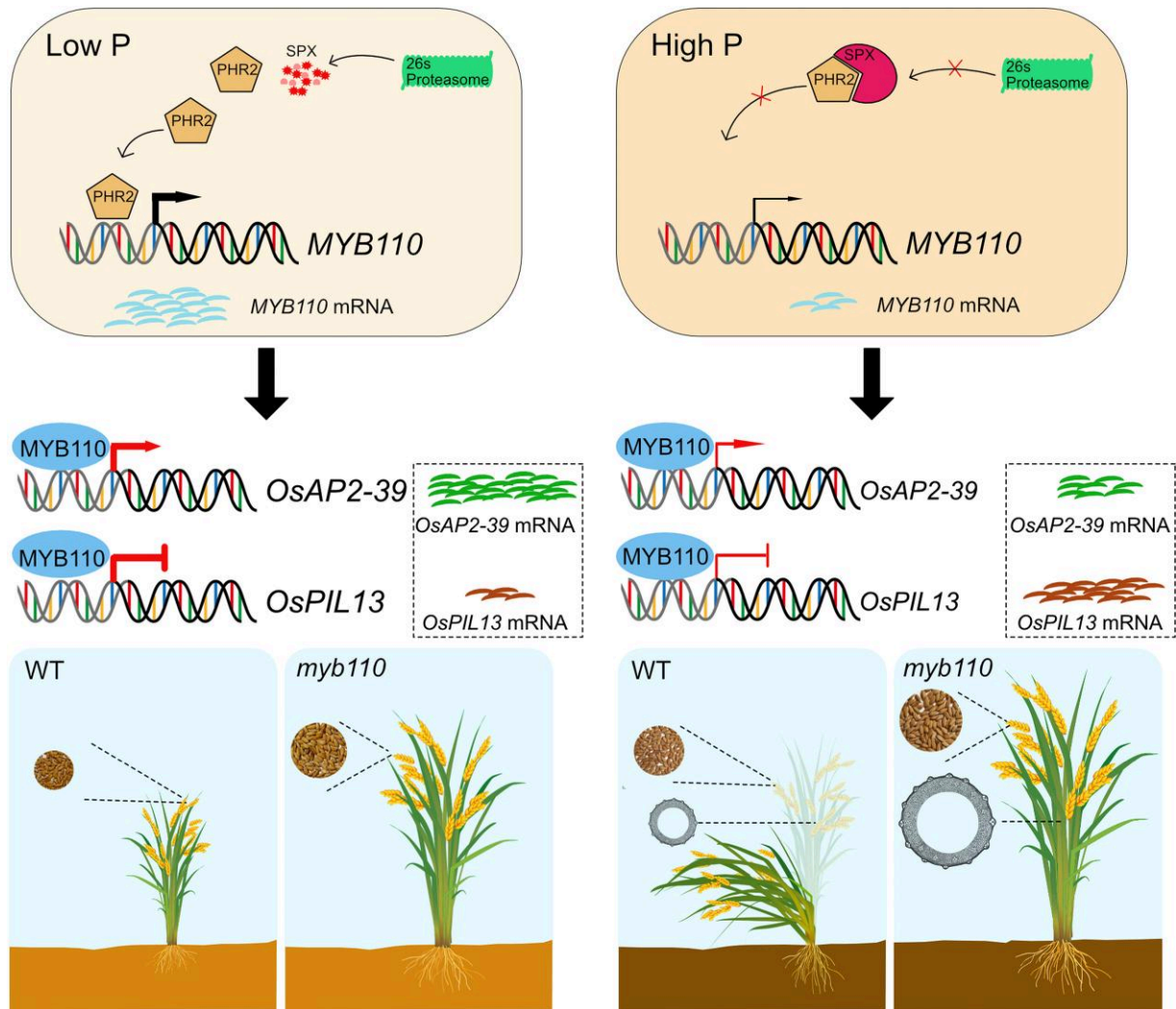
In this issue, **Tingting Wang and colleagues (Wang et al. 2023)** identified a Pi-dependent transcription factor, MYB110, that negatively regulates plant height and might provide an attractive strategy for breeding tall rice plants with lodging resistance and high yield (see Fig.). The authors found that MYB110 is induced under Pi starvation and swiftly repressed upon Pi resupply. Interestingly, the knockout mutant *myb110* plants were significantly taller than wild type, irrespective of soil Pi status, and the Pi starvation-induced inhibition of plant height was largely compromised upon MYB110 mutation. In contrast, growth in MYB110 overexpression (MYB110-Ox) lines was inhibited in both high- and low-Pi conditions. These findings suggest that MYB110 acts as a Pi-dependent negative regulator of plant height in rice.

The authors then focused on PHOSPHATE STARVATION RESPONSE 2 (PHR2), a central regulator of plant Pi starvation signalling identified in earlier studies (Zhou et al. 2008; Liu et al. 2010). Overexpression of *OsPHR2* retarded growth regardless of Pi availability. Interestingly, the authors detected a PHR1 binding sequence (P1BS) in the promoter of MYB110, suggesting that MYB110 could be a direct target of PHR2 in regulating plant height. Expression analysis of MYB110 in *phr2* mutant and PHR2-Ox lines suggested that PHR2 positively regulates MYB110 expression. Multiple follow-up assays confirmed that PHR2 physically binds to the P1BS motifs in the MYB110 promoter and that *OsPHR2* functions upstream of MYB110.

To identify MYB110's direct downstream genetic targets, the authors analyzed the promoter sequences of genes differentially regulated in *myb110* mutants. This analysis and further assays demonstrated that *OsAP2-39* and *OsPIL3* are direct targets of MYB110. Previous work demonstrated that *OsAP2-39* regulates ABA/GA balance to control plant height, and *OsPIL3* regulates internode elongation in rice (Yaish et al. 2010; Todaka et al. 2012).

Surprisingly, the *myb110* as well as the MYB110-Ox lines showed increased lodging resistance compared to the wild type under high-Pi conditions. Both *myb110* and MYB110-Ox lines showed increased resistance to bending of stem internodes compared with wild type. However, MYB110-Ox lines exhibited increased lignin deposition in the stem, whereas *myb110* mutants showed decreased lignin deposition but increased thickness between the inner and outer radius of the internode cross-section and in sclerenchyma cell layers. Hence, lodging resistance was attributed to reduced height and elevated lignification in MYB-Ox lines but the increased stem internode thickness in the taller *myb110* mutants (see Fig.).

The wild-type and MYB110-Ox plants exhibited significant yield penalties under low-Pi conditions compared with



**Figure.** A proposed working model of Pi-dependent MYB110-mediated regulation of plant height, lodging resistance, and yield in rice. MYB110 is a direct target of PHR2. MYB110 represses *OsPIL13* while activating *OsAP2-39* to regulate plant height in response to Pi supply. Knockout of MYB110 increases plant height, lodging resistance, grain size, and yield compared with wild type. Adapted from Wang et al. (2023), Fig. 10.

high-Pi conditions. In contrast, *myb110* mutant lines showed significantly higher yield under both low- and high-Pi conditions compared with wild type. Analyzing 270 rice samples, the authors identified 2 haplotypes comprising 4 SNPs in the MYB110 promoter and 1 in the ORF. Among the germplasm set, Indica cultivars were enriched with Hap1 and japonica cultivars with hap2. Genotypes with Hap2 showed higher MYB110 expression and shorter height compared with genotypes with Hap1.

Thus, the study by Wang et al. (2023) identified a distinct candidate gene that has the potential to increase plant height as well as increase lodging resistance and yield.

## References

Lambers H. Phosphorus acquisition and utilization in plants. *Annu Rev Plant Biol.* 2022;73:17–42. <https://doi.org/10.1146/annurev-arplant-102720-125738>

- Liu F, Wang Z, Ren H, Shen C, Li Y, Ling HQ, Wu C, Lian X, Wu P. OsSPX1 suppresses the function of OsPHR2 in the regulation of expression of OsPT2 and phosphate homeostasis in shoots of rice. *Plant J.* 2010;62(3):508–517. <https://doi.org/10.1111/j.1365-3113.2010.04170.x>
- Todaka D, Nakashima K, Maruyama K, Kidokoro S, Osakabe Y, Ito Y, Matsukura S, Fujita Y, Yoshiwara K, Ohme-Takagi M, et al. Rice phytochrome-interacting factor-like protein OsPIL1 functions as a key regulator of internode elongation and induces a morphological response to drought stress. *Proc Natl Acad Sci U S A.* 2012;109(39):15947–15952. <https://doi.org/10.1073/pnas.1207324109>
- Wang T, Jin Y, Deng L, Li F, Wang Z, Zhu Y, Wu Y, Qu H, Zhang S, Liu Y, et al. The transcription factor MYB110 regulates plant height, lodging resistance, and grain yield in rice. *Plant Cell.* 2024;36(2):298–323. <https://doi.org/10.1093/plcell/koad268>
- Yaish MW, El-Kereamy A, Zhu T, Beatty PH, Good AG, Bi YM, Rothstein SJ. The APETALA-2-like transcription factor OsAP2-39 controls key interactions between abscisic acid and gibberellin in rice. *PLoS Genet.* 2010;6(9):e1001098. <https://doi.org/10.1371/journal.pgen.1001098>
- Zhou J, Jiao FC, Wu Z, Li Y, Wang X, He X, Zhong W, Wu P. OsPHR2 is involved in phosphate-starvation signaling and excessive phosphate accumulation in shoots of plants. *Plant Physiol.* 2008;146(4):1673–1686. <https://doi.org/10.1104/pp.107.111443>