Breeding for enhanced P efficiency in rice

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**Question 1: what is our target environment?**

**Low input**
- low-P sandy soil
- typically no P fertilizer inputs
- drought likely
- Yield level 1.5 - 2 t/ha

**High input**
- fertile lowland soil
- high P fertilizer inputs
- irrigated
- Yield level 4 - 6 t/ha

Objective: increase yield by 1 t/ha  
Objective: maintain yield at reduced P application
P efficiency research & breeding: 2 scenarios

Improve P uptake and efficiency in low-input environments

- Upwards shift of P response curve at lowest end
- Improved response to small P inputs

Prevent yield reductions as P inputs decrease in high-input systems

- Extend plateau into lower P application
- ‘withdraw from bank’ of accumulated soil-P
P efficiency research & breeding: 2 scenarios

2. high-input scenario
   • Improved access to soil-bound P at high soil P content (‘wet sponge’) → prevent drop in P uptake

Where on the curve are we now?

- It can take several years until we have a yield reduction effect
- Because we simply reduce luxury P uptake in the first years

Is it being done?
P efficiency research & breeding: 2 scenarios

1. Improve P uptake and efficiency in low-input environments
   - Improved P uptake of P fixed in soil
   - Enhanced P utilization efficiency

![Graph showing grain yield vs. P uptake]
Summary

Low input:
• increase yield without additional input
• by enhancing P uptake and utilization
• assume multiple stresses limit yield (drought, N deficiency, toxicities...)
  ➢ Breeding efforts on their way

High input:
• yield reduction not acceptable, maintain yield at lower P input
• enhancing P uptake from P stored in soil
• and by accessing a higher proportion of fertilizer P
• long-term balance between P input and P removal
  ➢ Breeders is high-input focus on ‘more important’ issues
Genotypic variation for P efficiency exists within the rice germplasm. Traditional varieties are typically showing higher efficiency and uptake.

Can we identify specific root traits enhancing P uptake?
What is the ideal root type for P uptake?

Bigger is better?

Small but efficient?
What drives P uptake in rice – experimental evidence

Root size is the dominant factor for P uptake in rice
But genotypes with high root efficiency (RE: mg P uptake / root surface area) exist
Pup1 – a major P uptake QTL on chromosome 12
Major ‘P uptake gene’ at Pup1: *OsPSTOL1*

- OsPSTOL1 is a protein kinase mainly expressed at the earliest stages of crown root development
- Expression is typically upregulated under P deficiency
- The gene is completely absent in most modern rice varieties developed for favorite irrigated lowland conditions

*Gamuyao et al. 2012, Nature*
**PSTOL1 and crown root number**

- High expression of PSTOL1 is linked to crown root number
- The functional link remains unclear (kinase)

Move Pup1 / PSTOL1 to application in breeding
Pup1 – from research to application in breeding

Crossed Pup1 into IR64

- Very first data on IR64-Pup1 suggests it may work at medium-P range in irrigated lowlands
- This may be different as water supply decreases and soil types change
Marker assisted introgression into locally important rice varieties, done by local partners

Contacts: Dr. Chin at IRRI for IR64-Pup1 donors
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Phosphorus flows in **low-input** crop production

80% of plant P is in the grain

- **Erosion**
- **Removal of P in grain**
- **Mining of soil P reserves**
- **Pollution**
Phosphorus flows in high-input crop production

Removal of P with seeds drives pollution, need for P fertilization to balance take-off, or loss of soil fertility.
Seed P facts

• Every year about 2.1 Mt of fertilizer phosphorus (P) are applied to rice at a cost exceeding US$ 11 Bn
• The global rice crop removes about 1.5 Mt P annually = a ‘loss’ of P equivalent to about US$ 7.5 Bn !!
• Reducing seed-P concentrations by 20% could save US$ 1.5 Bn annually in P fertilizer costs
• Or help maintain soil fertility in low-input farming
• And reduce pollution

So why has nobody worked on that?

Concerns that reduced seed-P reserves will affect seedling vigor
Does seed-P affect seedling vigor?

• Produce batches of seed with different seed-P concentrations (within genotypes)
• Seedling biomass at 3-5 WAS
  ➢ No effect of seed P on vigor and yield on ‘normal’ soil (2-year data, 6 varieties)

• Transplant to ‘normal’ paddy field after raising seedlings in different medium
  ➢ No effect on grain yield

• But possibly small negative effects on P deficient soils
• Genotype-specific (general seedling vigor?)

Fears about loss of productivity due to low seed-P reserves are overstated
Pyramiding genes controlling complementary P efficiency traits

- **P acquisition efficiency**
  - **P uptake efficiency**
  - **P utilization efficiency**
  - **Candidate genes**
  - **GWAS and G x E**
  - **MAS ongoing**

### Levels of the Pyramide

1. **ROOT TRAITS**
   - **ROOT HAIRS**
   - **ROOT BRANCHING**
   - **ROOT ANGLE**

2. **P ACQUISITION EFFICIENCY**
   - **ROOT EXUDATES: P SOLUBILIZATION & PLANT-MICROBE INTERACTIONS**

3. **PUE**
   - **P UTILIZATION EFFICIENCY**
   - **SEED-P**
     - **REDUCE SEED P CONCENTRATIONS**

4. **PUP1**
   - **Candidate genes**

5. **MAS ongoing**
   - **GWAS and G x E**

### Key Terms
- **Donors, crosses, physiology**
- **Candidate genes**
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