Genotypic differences in phosphate utilization efficiency (PUE) and photosynthetic efficiency under P starvation and metabolic markers for high PUE

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Abstract

Utilizing phosphate more efficiently is crucial for sustainable crop production. Highly efficient rice (Oryza sativa) cultivars have been identified and this study aims to identify metabolic markers associated with P utilization efficiency. P deficiency generally reduced leaf P concentrations and CO2 assimilation rates but efficient cultivars were reducing leaf P concentrations further than inefficient ones while maintaining similar CO2 assimilation rates. Adaptive changes in carbon metabolism were detected but equally in efficient and inefficient cultivar groups. Groups furthermore did not differ with respect to partial substitutions of phospholipids by sulfo- and galactolipids. Metabolites significantly more abundant in the efficient group, such as sinapate, benzoate and glucoronate, were related to antioxidant defense and may help alleviating oxidative stress caused by P deficiency. Sugar alcohols ribitol and threitol were another marker metabolite for higher phosphate efficiency as were several amino acids, especially threonine. Since these metabolites are not known to be associated with P deficiency, they may provide novel clues for the selection of more P efficient genotypes. In conclusion, metabolite signatures detected here were not related to phosphate metabolism but rather helped P efficient lines to keep vital processes functional under the adverse conditions of P starvation.

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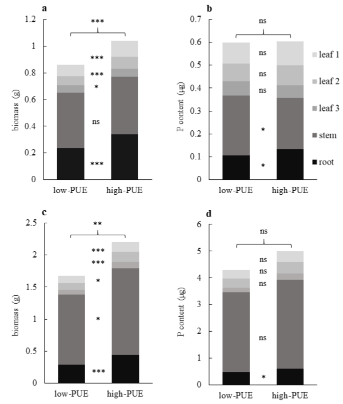


Figure 1 Biomass and P content under low P supply (panels a and b) and high P supply (panels c and d) in different plant tissues. Leaf 1 represents the youngest fully expanded leaf with leaf 2 and 3 being the next youngest leaves. ***, **, * indicate significant differences at the 0.001, 0.01 and 0.05 levels (LSD) for the respective tissues between the high-PUE and low-PUE groups of genotypes (ns = not significant).

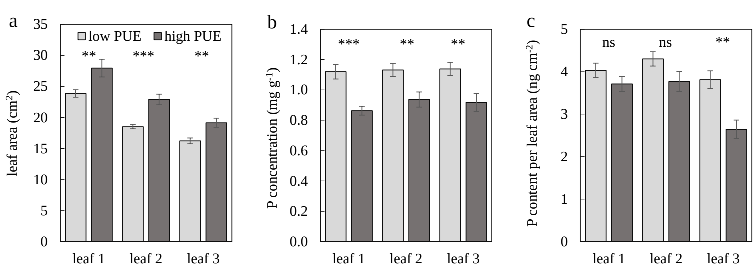


Figure 2 Leaf area, leaf P concentrations and P content per cm^2 leaf area of the three youngest leaves under low P supply. ***, **, * indicate significant differences at the 0.001, 0.01 and 0.05 levels for the respective tissues between the high-PUE and low-PUE groups of genotypes (ns = not significant).

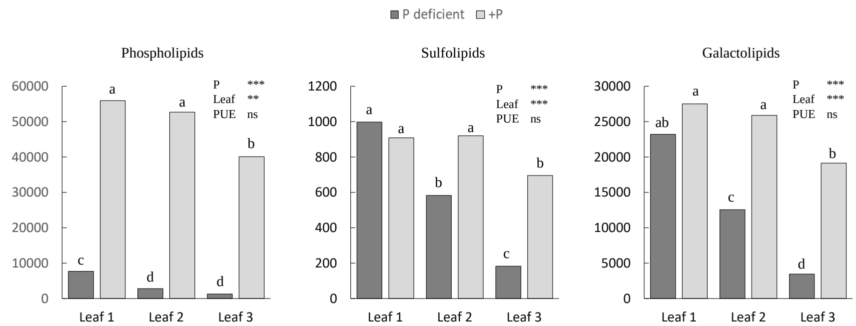
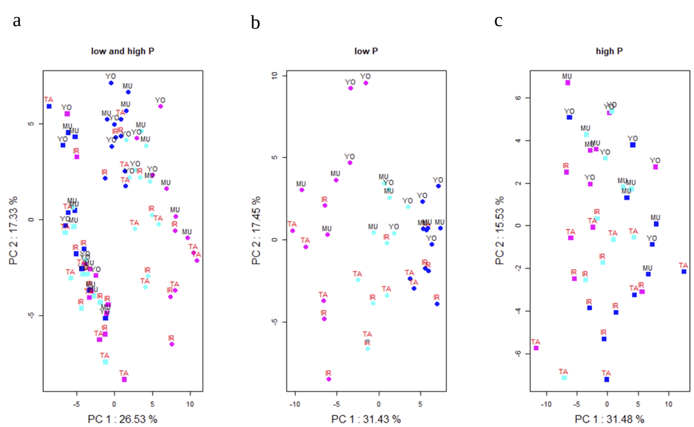
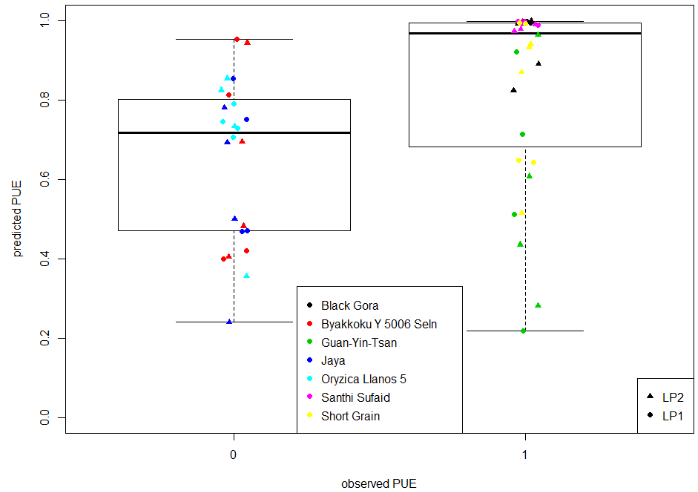
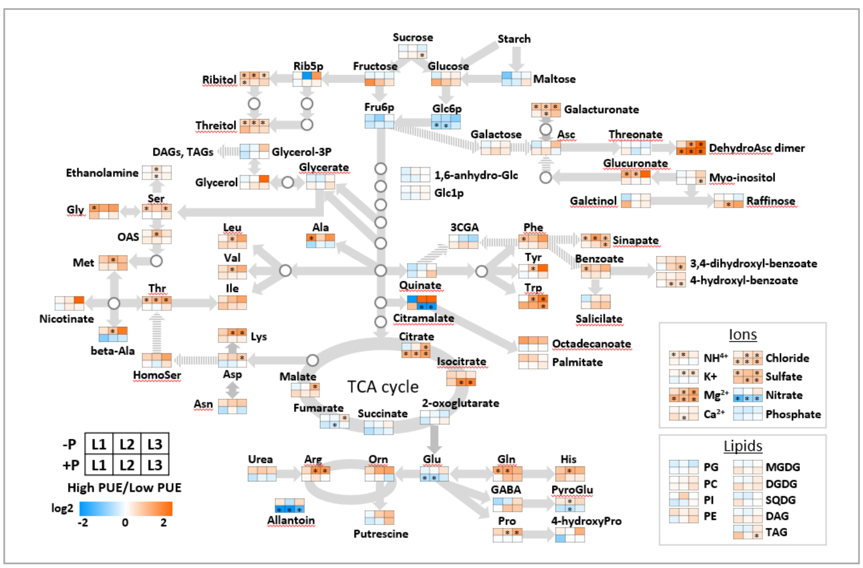


Figure 3 Changes in lipid composition in response to P deficiency in the three youngest leaves. Differences between the high-PUE and low-PUE groups were minor and not significant and therefore means across groups are shown. Letters above bars indicate significant differences at $p < 0.05$. Values on Y-axis indicate relative peak height (in thousands). Peak heights of the mass fragments were normalized based on the fresh weight of the sample and the value of internal standard.




predicted PUE
0.0
0.2
0.4
0.6
0.8
1.0
0
1
observed PUE
Black Gora
Byakkoku Y 5006 Seln
Guan-Yin-Tsan
Jaya
Oryzica Llanos 5
Santhi Sufaid
Short Grain
LP2
LP1


Sucrose
Starch
Rib5p
Fructose
Glucose
Ribitol
Maltose
Fru6p
Glc6p
Galacturonate
Threitol
Galactose
Asc
Threonate
DehydroAsc dimer
DAGs, TAGs
Glycerol-3P
Glycerate
Glucuronate
Ethanolamine
Glycerol
1,6-anhydro-Glc
Myo-inositol
Glc1p
Galctinol
Raffinose
Ser
Gly
OAS
Leu
Ala
3CGA
Phe
Sinapate
Met
Val
Tyr
Benzoate
3,4-dihydroxyl-benzoate
4-hydroxyl-benzoate
Thr
Ile
Quinate
Trp
Nicotinate
Citramalate
Salicilate
beta-Ala
Lys
Citrate
Octadecanoate
Palmitate
HomoSer
Asp
Malate
Isocitrate
TCA cycle
Asn
Fumarate
Succinate
2-oxoglutarate
Ions
NH4+
Chloride
K+
Sulfate
Mg2+
Nitrate
Ca2+
Phosphate
-P
+P
L1
L2
L3
High PUE/Low PUE
log2
-2
0
2
Urea
Arg
Orn
Glu
Gln
His
GABA
PyroGlu
Allantoin
Pro
4-hydroxyPro
Putrescine
Lipids
PG
MGDG
PC
DGDG
PI
SQDG
PE
DAG
TAG