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SHORT COMMUNICATION

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Effect of phosphorus nutrition and grain position within maize cob on grain phosphorus accumulation

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Abstract

Nutritional status of grains may vary due to external nutrient supply and their position within parent maize cob. Phosphorus (P) is the least mobile nutrient in the soil and therefore newly growing seedlings are largely dependent on the stored grain P contents which are accumulated during the crop maturity period. Objective of this study was to access the effects of different P applications and grain positions on P and dry matter contents in grains. Phosphorus application and grain position has significant ($p < 0.05$) effects on P contents in grains whereas dry weight and P content are highly correlated. Grain weight and P contents decreased linearly from base to apical position possibly due to flow of nutrients from base towards apical position within cob. Significantly higher grain dry weight (0.35 ± 0.01 g) and P contents (962 ± 57 µg P) are recorded in high P application (92.50 kg ha^{-1}) rate on base position whereas minimum grain dry weight (0.14 ± 0.01 g) and P contents (219 ± 11 µg P) were recorded on apical grain position in low P application (5.60 kg ha^{-1}) rate. The results suggest that for better seedling P nutrition especially in soils of low inherent P, maize grains should be selected from base or middle position where maximum dry weight and P contents are concentrated to support the seedlings to reach at growth at which roots are capable of external P uptake.

Additional key words: grain P; grain position; P contents; P application.

Phosphorus is the second most important macronutrient for the plant growth and comprises approximately 0.2% of a plant's dry weight (Schachtman *et al.,* 1998). It plays a critical role in plant metabolism, cellular energy transfer, respiration and photosynthesis (Glass *et al.*, 1980; Ozanne, 1980; Deleens *et al.,* 1984; He & Burris, 1992; Usuda & Shimogawara, 1993; Bewley, 1997; Bathellier *et al.,* 2007). In seeds, P is stored primarily in the form of phytate (Lott *et al.,* 1995; Park *et al.,* 2006; Nadeem *et al.,* 2011). Phytate is considered as having anti-nutrient characteristics when consumed by non ruminant animals (Raboy *et al.,* 1989). Phytate content of cereals is highly correlated with total P (Lockhart & Hurt, 1986), and P concentrations in seeds of a given species may vary with cultivar, inherent soil P status, and climatic conditions (Miller *et al.,* 1980; Raboy *et al.,* 1990; Horvatic & Balint, 1996).

Seed vigor is an important determinant of final crop harvest and depends upon the status of the stored nutrients in seeds. Seed vigor deals with the ability of seed to grow rapidly and uniformly under unfavorable conditions (Hara & Toriyama, 1998). Therefore, the rate of initial seedling growth is often used as an index to quantify seed vigor (Seshu *et al.,* 1988), which implies that the acceleration of the rate of germination is important to enhance the seedling establishment. It is generally recognized that increase of seed dry weight and other nutrients improves the seed vigor (Seshu *et al.*, 1988; Thomson & Bolger, 1993; Ros *et al.,* 1997; Modi & Asanzi, 2008). Seed germination, seed vigor and seedling establishment are therefore three

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Abbreviations used: HP (high phosphorus content); IP (intermediate phosphorus content); LP (low phosphorus content).

important characters which depend on the seedling ability to utilize stored seed reserves more efficiently (Bedi *et al.,* 2009).

Size and shape vary widely within a batch of grains/seeds. Space between grains on cob decreases from the base to top, therefore affecting the shape of grains and their nutritional status as well (Pommel *et al.,* 1995). In maize constraints experienced by the grain position during cob formation such as nutritional deficiencies may decrease the size of the grain on cob. The resulted grains are less in nutritive values (Pommel *et al.,* 1995) to support the seedlings during early ontogeny. Consequently it is possible that grain position on cob may affect the P status of seeds that it produces (Pommel *et al.,* 1995). For optimum crop yield, plants require adequate P from very early growth stages (Barry & Miller, 1989; Barry *et al.,* 1989; Grant *et al.,* 2001). The success or failure of the early growth stage of developing seedlings is directly related to successful remobilization of stored grain P reserves that were accumulated throughout the ripening period (Guardiola & Sutcliffe, 1971; Le Deunff, 1975; Lawrence *et al.,* 1990; Leonova *et al.,* 2010; Nadeem *et al.,* 2011, 2012a). As the hydrolysis of grain P during germination is a major source of inorganic P to support the growing seedlings during early growth stages (Nadeem *et al.,* 2011; 2012b) therefore the present study was conducted to investigate the role of P nutrition to the parent plant on the dry weight and P reserves accumulation in maize grains for better selection of seeds.

The irrigated maize crop (*Zea mays* L. cv. DKc 5783, Dekalb, Monsanto Agricoltura SpA, Lodi, Italy) was cultivated at the experimental site of Pierroton, Bordeaux, in southwest France (44° 44' 30" N; 0° 46' 59" W; alt. 55 m) during 2009-10. The maize crop was fertilized with triple superphosphate (45% P_2O_5). Phosphorus was applied in three P rates as low P (LP: 5.6 kg ha^{-1}), intermediate P (IP: 23.10 kg ha^{-1}) and high P (HP: 92.50 kg ha^{-1}) to get three levels in maize seeds. Soil analysis showed that available Olsen-P in ploughed soil layer (0-0.25 m) was 5.50 mg P kg^{-1}, 9.90 mg P kg^{-1} and 40.50 mg P kg^{-1} of dry soil for LP, IP and HP, respectively. At maturity, the maize cobs were harvested from the field and separated in LP, IP and HP fertilization treatments. Five maize cobs were selected from each treatment randomly to select homogenous grains from these cobs. The P treatments were not replicated and one plot corresponds to one P treatment. For each P treatment, 5 plants were randomly selected (with at least 5 m between each plant). One cob per plant was harvested for P analysis. So the 5 samples correspond to the 5 harvested cobs per P treatment. For each cob, several grains were collected according their position, but they were considered as subsamples. During the study, the maize grains were separated into three categories namely apical, middle and base grains as shown in Fig. 1a.

Each position on cob corresponds to 1/3 of the total cob length. Out of these three categories, homogenous maize grains were separated and total 27 grains were selected and pooled for the three grain positions respectively and for the five cobs per P treatment. The selected grains were dried in oven at 130°C for 24 h and thereafter these grains were placed in desicator. Grain dry weight was measured after lyophilization for 24 h. Phosphorus contents were determined in maize grains after mineralization (see Nadeem *et al.,* 2011, for details) by an adaptation of malachite green colorimetric technique (Van Veldhoven & Mannaerts, 1987). The resulted data were analyzed by ANOVA using the R environment for statistical computing and graphics, version 2.9.1 (R Development Core Team, 2009). Means were compared using Tukey's test at the 0.05 risk level.

Fig. 1b shows that plots (assumed to mainly differ in phosphorus nutrition) along with grain position within maize cob has significant ($p < 0.05$) effects on dry weight accumulation in grains at maturity. At each position on maize cob, grain weight increases linearly from low P application to higher P application and base position of grains. Maximum grain dry weight (0.35 ± 0.01 g) at maturity was recorded at base position followed by the middle grains position (0.31 ± 0.01 g) when high P was applied to crop. Grain weight decreases with the low P fertilizer applications and minimum grain weight was observed at apical position (0.14 ± 0.01 g) when crop was fertilized with low P inputs. No increase in grain weight at middle position was observed (0.20 ± 0.02 g) in the intermediate-P plot compared the high P plot with (Fig. 1b).

Significant differences were observed among plots and grain positions on final grain P contents, as shown in Fig. 1c. Higher P application caused an increased P contents in maize grains followed by IP and LP applications. Similarly grain P contents decreased linearly from base to apical positions. Maximum grain P contents (962 ± 57 µg) were

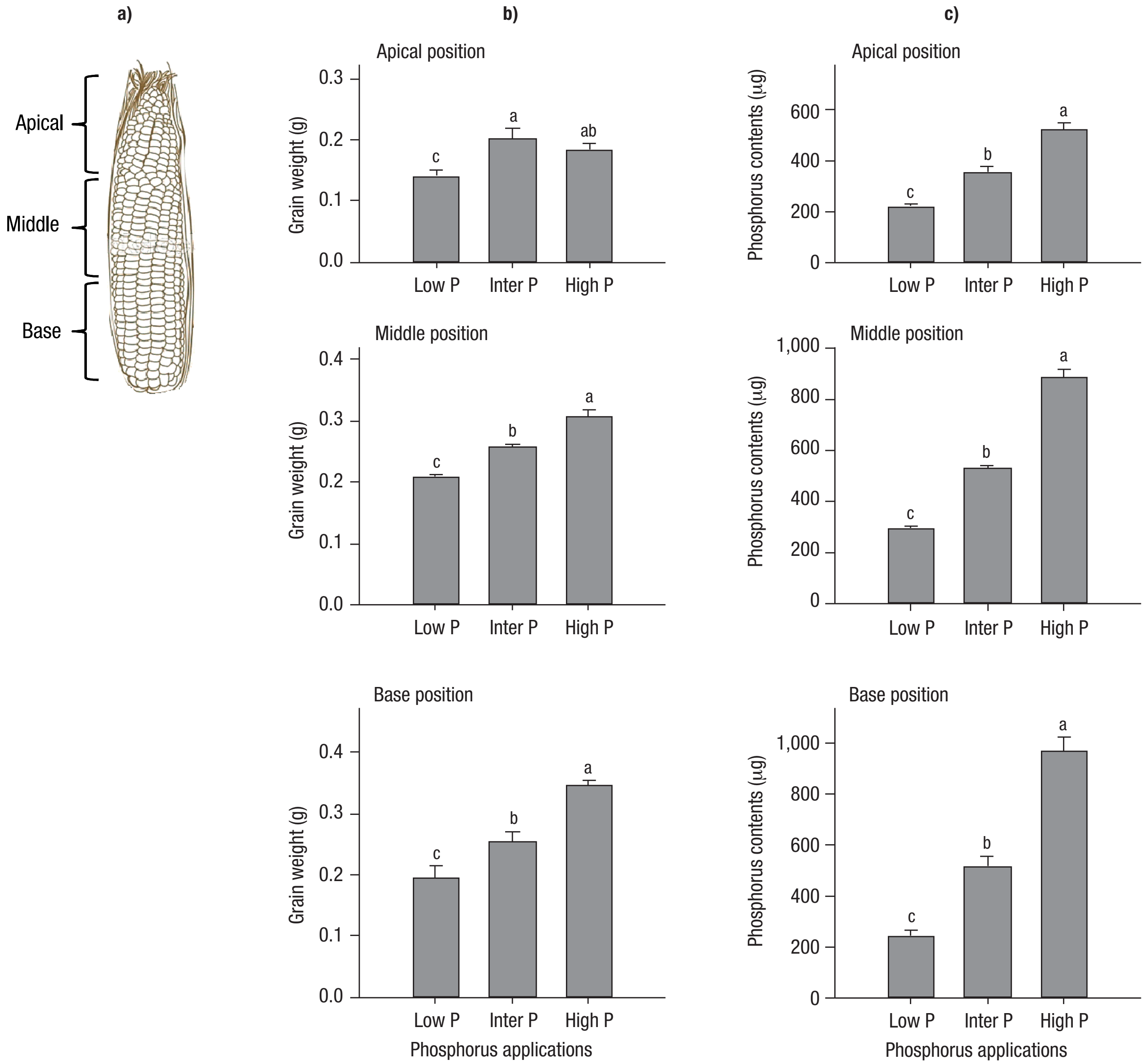

Figure 1. Selection of maize grains on cob (a) for phosphorus. Effect of different phosphorus applications and grain position on the final grain weight (in grams) (b) and on the final grain phosphorus contents (µg) (c). Data are means and vertical bars indicate ±SE for $n = 5$ replications. Different letters indicate a significant difference between P level (Student's *t*-test, $p < 0.05$)

observed at base position followed by middle position (883 ± 33 µg) when crop received HP applications as shown in Fig. 1c. Minimum grain P contents were noticed at apical grain position (219 ± 11 µg) followed by base (242 ± 22 µg) and middle positions (295 ± 8 µg) when LP was applied during the growing seasons as indicated in Fig. 1c (apical, base and middle, respectively).

Phosphorus being a component of living cells is essential to sustains life (Rengel & Zhang, 2011; Six, 2011). Phosphorus accumulates rapidly in grains during ripening along with other substances such as lipids and starch. In seeds, phytate is the main stored form of P (Raboy *et al.,* 1989; Ravindran *et al.,* 1994; Lott *et al.,* 1995; Park *et al.,* 2006; Nadeem *et al.,* 2011) along with inorganic and cellular P (Raboy *et al.,* 2001). External P supply has significant effects on P and dry matter accumulation in grains phosphorus contents are significantly higher in grains treated with HP availability as compared to IP or LP. Phosphorus content in seeds depends both on external P availability and grain biomass accumulation. A relationship was

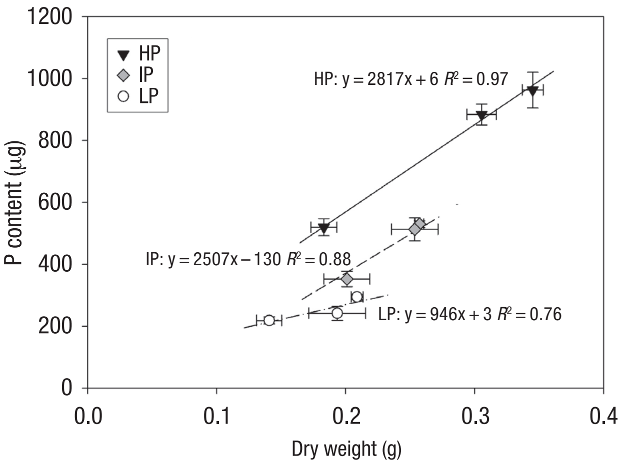

Figure 2. Relationship between dry weight and phosphorus accumulation per grain when irrigated maize crop was treated with three P nutritional levels. Data are means and vertical bars indicate ±SE for n = 5 replications.

observed between grain dry matter and P content within each P availability level as shown in Fig. 2. As grain weight decreased from base towards apical position, the accumulation of P was negatively affected as less P was accumulated in IP and LP (Fig. 2). So, phosphorus content in grains is driven by the dry biomass accumulation and is dependent on the plant P nutrition. Grain position within the maize cob also affects the P contents. Higher grain P contents were observed in grains located at base position as compared to middle or apical grains possibly due to the flow of nutrients from base position towards apical. This may also be related to the distance between P source in root zone and grain position (P sink) resulting into larger grains at base position compared to middle or apical. Previous research showed that size of maize grain can influence the nutritional status (micro and macro-nutrients) of grains (Calderini & Ortiz-Monasterio, 2003; Baraloto *et al.,* 2005; Hanley *et al*., 2007; Zhang *et al*., 2012) and consequently the growth of seedlings. Larger grains with larger nutritional reserves are capable of producing vigorous plants (Howe & Schupp, 1985; Ellison, 1987; Pommel *et al.,* 1995; Nadeem *et al.,* 2012a). Seedling emergence was more rapid in seeds with higher P concentrations compared to seeds with low P status (De Marco, 1990; Pommel *et al.,* 1995). Crop grains have large enough P reserves to sustain seedling P requirement during a few weeks of early growth (White & Veneklaas, 2012), however grains with higher indigenous P reserves can support seedling growth for a longer period of time (Nadeem *et al.,* 2012a) especially on soils with low inherent P levels. Higher P contents per seed were observed in basal grains in HP treatment. The results suggest that taking into consideration the position of grains in the cob and their P contents could be an important tool for selection of grains producing vigorous seedling growth. The study was carried out only in one growing season, one planting date and one location, consequently the results presented need to be verified in a wider range of field conditions.

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References

Barry DAJ, Miller MH, 1989. Phosphorus nutritional-requirement of maize seedlings for maximum yield. Agron J 81: 95-99.

Barry DAJ, Miller MH, Bates TE, 1989. Ear leaf and seedling-P concentration and dris indexes as indicators of P-nutrition for maize. Commun Soil Sci Plant Anal 20: 1397-1412.

Baraloto C, Forget PM, Goldberg DE, 2005. Seed mass, seedling size and neotropical tree seedling establishment. J Ecol 93:1156-1166.

Bathellier C, Badeck F, Couzi P, Harscoët S, Mauve C, Ghashghaie J, 2007. Divergence in $\delta^{13}C$ of dark respired CO_2 and bulk organic matter occurs during the transition between heterotrophy and autotrophy in *Phaseolus vulgaris* plants. New Phytol 177: 406-418.

Bedi S, Mehta S, Sharma S, Vashist KK, 2009. Nitrogen nutrition and efficiency of seed reserve mobilization during germination in winter maize cv. 'Buland'. J New Seeds 10: 57-61.

Bewley JD, 1997. Seed germination and dormancy. Plant Cell 9: 1055-1066.

De Marco DG, 1990. Effect of seed weight, and seed phosphorus and nitrogen concentrations on the early growth of wheat seedlings. Aust J Exp Agric 30: 545-549.

Deleens E, Gregory N, Bourdu R, 1984. Transition between seed reserve use and photosynthetic supply during development of maize seedlings. Plant Sci Lett 37: 35-39.

Calderini DF, Ortiz-Monasterio I, 2003. Grain position affects grain macronutrient and micronutrient concentrations in wheat. Crop Sci 43: 141-151.

Ellison AM, 1987. Effect of seed dimorphism on the density dependent dynamics of experimental population of *Antiplex trianularis* (Chenopodiaceae). Amer J Bot 74: 1280-1288.

Glass ADM, Beaton JD, Bomke A, 1980. Role of P in plant nutrition. Proc Western Canada Phosphate Symposium. pp: 357-368.

Grant CA, Flaten DN, Tomasiewicz DJ, Sheppard SC, 2001. The importance of early season phosphorus nutrition. Can J Plant Sci 81: 211-224.

Guardiola JL, Sutcliffe JF, 1971. Mobilization of phosphorus in the cotyledons of young seedlings of the garden pea (*Pisum sativum* L.). Ann Bot 35: 809-823.

Hanley ME, Cordier PK, May O, Kelly CK, 2007. Seed size and seedling growth: differential response of Australian and British Fabaceae to nutrient limitation. New Phytol 174: 381-388.

Hara Y, Toriyama K, 1998. Seed nitrogen accelerates the rates of germination, emergence, and establishment of rice plants. Soil Sci Plant Nutr 44(3): 359-366.

He LS, Burris JS, 1992. Respiration and carbohydrate-metabolism during germination of *sh2* and *Sh2* sweet corn seed. Hortscience 27: 1306-1308.

Horvatic M, Balint L, 1996. Relationship among the phytic acid and protein content during maize grain maturation. J Agron Crop Sci 176: 73-77.

Howe HF, Schupp EW, 1985. Early consequence of seed dispersal for a neotrophical tree (*Viola surinamensis*). Ecol 66: 781-791.

Lawrence DM, Halmer P, Bowles DJ, 1990. Mobilisation of storage reserves during germination and early seedling growth of sugar beet. Physiol Plant 78: 421-429.

Le Deunff Y, 1975. La régulation hormonale de la germination: le cas des céréales. In: La germination de semences (Chaussat R & Le Deunff Y, eds). Gauthier Villars, Paris. pp: 81-93.

Leonova S, Grimberg A, Marttila S, Stymne S, Carlsson AS, 2010. Mobilization of lipid reserves during germination of oat (*Avena sativa* L.), a cereal rich in endosperm oil. J Exp Bot 61: 3089-3099.

Lockhart HB, Hurt HD, 1986: Nutrition of oats. Am Assoc of Cereal Chemists, St. Paul, MN, USA. pp: 297-308.

Lott JNA, Greenwood JS, Batten GD, 1995. Mechanisms and regulation of mineral nutrient storage during seed development. Marcel Dekker, NY. pp: 215-235.

Miller GA, Youngs VL, Oplinger ES, 1980. Effect of available soil-phosphorus and environment on the phytic acid concentration in oats. Cereal Chem 57: 192-194.

Modi AT, Asanzi NM, 2008. Seed performance of maize in response to phosphorus application and growth temperature is related to phytate-phosphorus occurrence. Crop Sci 48: 286-297.

Nadeem M, Mollier A, Morel C, Vives A, Prud'homme L, Pellerin S, 2011: Relative contribution of seed phosphorus reserves and exogenous phosphorus uptake to maize (*Zea mays* L.) nutrition during early growth stages. Plant Soil 346: 231-244.

Nadeem M, Mollier A, Morel C, Vives A, Prud'homme L, Pellerin S, 2012a. Maize (*Zea mays* L.) endogenous seed phosphorus remobilization is not influenced by exogenous phosphorus during germination and early growth stages. Plant Soil 357: 13-24.

Nadeem M, Mollier A, Morel C, Vives A, Prud'homme L, Pellerin S, 2012b. Seed phosphorus remobilization is not a major limiting step for phosphorus nutrition during early growth of maize. J Plant Nutr Soil Sci 175: 805-809.

Ozanne PG, 1980. Phosphate nutrition of plants - A general treatise. ASA, Madison, WI, USA. pp: 559-589.

Park SH, Sung JK, Lee SY, Park JH, Lee JY, Jang BC, Lee BH, Kim TW, 2006. Early growth, carbohydrate, and phytic acid contents of germinating rice seeds under NaCl stress. Korean J Crop Sci 51: 137-141.

Pommel B, Goytino B, Bonhomme R, 1995. Effects of seed size, seed position on the parent cob and parental cob size on the leaf area of maize under field conditions. Eur J Agron 4: 363-369.

R Development Core Team, 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available in http://www.r-project.org/. [Accessed 4 Feb 2012].

Raboy V, 1990. Biochemistry and genetics of phytic acid synthesis. In: Inositol metabolism in plants (Morré DJ, Boss WF & Loewus FA, eds). Wiley Liss Inc, NY. pp: 55-76.

Raboy V, Below FE, Dickinson DB, 1989. Alteration of maize kernel phytic acid levels by recurrent selection for protein and oil. J Hered 80: 311-315.

Raboy V, Young KA, Dorsch JA, Cook A, 2001. Genetics and breeding of seed phosphorus and phytic acid. J Plant Physiol 158: 489-497.

Ravindran V, Ravindran G, Sivalogan S, 1994. Total and phytate phosphorus contents of various foods and feedstuffs of plant origin. Food Chem 56: 335-343.

Rengel Z, Zhang F, 2011. Phosphorus sustains life. Plant Soil 349: 1-2.

Ros C, Bell RW, White PF, 1997. Effect of seed phosphorus and soil phosphorus applications on early growth of rice (*Oryza sativa* L.) cv IR66. Soil Sci Plant Nutr 43: 499-509.

Schachtman DP, Reid RJ, Ayling SM, 1998. Phosphorus uptake by plants: From soil to cell. Plant Physiol 116: 447-453.

Seshu DV, Krishnaswamy V, Siddique SB, 1988. Seed vigour in rice. In: Rice seed health. International Rice Research Institute, Manila. pp: 315-329.

Six J, 2011. Plant nutrition for sustainable development and global health. Plant Soil 339: 1-2.

Thomson CJ, Bolger TP, 1993. Effects of seed phosphorus concentration on the emergence and growth of subterranean clover (*Trifolium subterraneum* L.). Plant Soil 156: 285-288.

Usuda H, Shimogawara K, 1993. Phosphate deficiency in maize. III. Changes in amounts of sucrose-phosphate synthase during phosphate deprivation. Plant Physiol 102: 176-176.

Van Veldhoven PP, Mannaerts GP, 1987. Inorganic and organic phosphate measurements in the nanomolar range. Anal Biochem 161: 45-48.

White PJ, Veneklaas EJ, 2012. Nature and nurture: the importance of seed phosphorus content. Plant Soil 357: 1-8.

Zhang Y, Zhang Y, Liu N, Su D, Xue Q, Stewart BA, Wang Z, 2012. Effect of source-sink manipulation on accumulation of micronutrients and protein in wheat grains. J Plant Nutr Soil Sci 175: 622-629.