OPEN ACCESS
Pakistan Journal of Agricultural Research

Research Article

Prospective of Use of Phosphorus and Zinc at Tillering and Booting Stages of Rice

Farah Rasheed[1*], Ana Aslam[1], Muhammad Aftab[1], Ghulam Sarwar[2], Raheela Naz[1], Hina Nazir[3], Sadia Sultana[1], Amina Kalsom[1], Nisa Mukhtar[1], Ifra Saleem[1], Qudsia Nazir[1], Muhammad Arfan-ul-Haq[1], Abid Niaz[4], Muhammad Arif[1], Aamer Sattar[1], Sarfraz Hussain[5] and Adnan Rafique[6]

[1]Soil Chemistry Section, Institute of Soil Chemistry and Environmental Science, Ayub Agriculture Research Institute, Faisalabad, Punjab, Pakistan; [2]College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan; [3]Soil and Water Testing Laboratory, Faisalabad, Punjab, Pakistan; [4]Provincial Reference Fertilizer Testing Laboratory, Raiwind, Lahore, Punjab, Pakistan; [5]Institute of Soil Chemistry and Environmental Sciences, Kala Shah Kaku, Punjab, Pakistan; [6]Pesticide Quality Control Lab., Kala Shah Kaku, Lahore, Pakistan.

Abstract | Phytic acid is substance that stores most of phosphorus in seeds of many cereals. It is a strong chelating agent which can chelate essential nutrients like zinc, iron, calcium and magnesium resulting in mineral deficiency in masses of developing countries. Low phytic acids is therefore a primary factor to enhance availability of these nutrient and combat phytic acid related issues. In this study, the most suitable crop stage and combination of zinc and phosphorus application was investigated to decrease phytin content and enhance zinc bioavailability in rice grain. Three level of phosphorus fertilizer viz. 60, 90, 120 kg ha^{-1} were employed with 5 and 10 kg ha^{-1} of zinc fertilizer. Treatment applied with the recommended dose of nitrogen, phosphorus and potassium was taken as control. Paddy yield data were collected and rice grain was analysed for phosphorus, zinc and phytic acid contents. Findings showed that maximum paddy yield (4.80 t ha^{-1}) was found where P and Zn were applied 120 and 5 kg ha^{-1} respectively with maximum P (0.55%), Zn (13.8 mg kg^{-1}) and phytic acid (0.38%) contents. Lowest phytic acid contents (0.32%) were observed in control treatment. The results depicted that yield, P and Zn contents of rice grain improved significantly due to synergistic effect of P and Zn fertilizers applied at different growth stages. The phytic acid contents in rice grains remained within safe limit in all treatments but lower grain phytic acid have been observed where only recommended dose of NPK fertilizers were used.

Received | December 10, 2021; **Accepted** | June 23, 2022; **Published** | June 28, 2022
***Correspondence** | Farah Rasheed, Soil Chemistry Section, Institute of Soil Chemistry and Environmental Science, Ayub Agriculture Research Institute, Faisalabad, Punjab, Pakistan; **Email:** farah.fatima9@gmail.com
Citation | Rasheed, F., A. Aslam, M. Aftab, G. Sarwar, R. Naz, H. Nazir, S. Sultana, A. Kalsom, N. Mukhtar, I. Saleem, Q. Nazir, M.A. Haq, A. Niaz, M. Arif, A. Sattar, S. Hussain and A. Rafique. 2022. Prospective of use of phosphorus and zinc at tillering and booting stages of rice. *Pakistan Journal of Agricultural Research,* 35(2): 394-403.
DOI | https://dx.doi.org/10.17582/journal.pjar/2022/35.2.394.403
Keywords | Yield, Quality, Phytic acid, Mineral nutrition, Oryza sativa

Introduction

Mineral fertilizer of phosphorus provides high crop yield. Global phosphorus fertilizer consumption has raised from 4.6 million tonns in 1961 to an estimated 22-27 million tonns phosphorus per year by 2050 (Bindraban *et al*., 2020). Phosphorus is a primary nutrient that is required by plants in larger quantities for plant structure and functions i.e., cell division, root development, flowering, fruit and seed formation. However, usually it is less available to plants, which affects plant productivity. P is redistributed in source and sink organs of plants to enhance its utility and homeostasis. In case of P deficiency, P is relocated from older leaves to younger leaves while during reproductive season, P is redistributed from vegetative parts to seeds and converts into phytic acid in cereals (Perera *et al*., 2019). P can be remobilized up to 25–30% from vegetative organs to the grain (Xie *et al*., 2018).

Phytic acid (PA) is almost impenetrable in human body and most occurring substance of phosphorus in seeds. Genetic modification can reduce level of phytic acid in rice and enhance nutritional value of crop (Larson *et al*., 2000). PA stores in seeds, nuts, legumes and grains in fairly high quantity on weight basis, about 1-5% of human needs. About 70% of its weight is made of P. It can attach iron, zinc and calcium along with other ions (Garcia-Estepa *et al*., 1999; Raboy *et al*., 2000; Erdal *et al*., 2002; Mate and Radomir, 2002; Gallaher, 2012; Nissar *et al*., 2017; Perera *et al*., 2018), which can cause deficiency of micronutrients in food due to less diversity in available food. PA is present up to 5% in some brans increasing its chances to be in food chain. Marginal availability of micronutrients enhances due to the presence of PA. It converts into other inositol phosphates during metabolic processes in the gut, IP5 and IP6 fixes nutrients. PA is present from 4-7 mg g^{-1} in rice, oat, barley and rye (Garcia-Estepa *et al*., 1999).

About 2 million people suffer from micronutrient deficiency (FAO, 2014), moreover, micronutrient deficiency is more prevalent in developing states (IFPRI, 2016). Nutrient scarcity of zinc and iron, due to tendency of phytic acid to bind them, make them unavailable to human digestive system. These nutrients are indispensable for proper development and growth of human body. Cooking can lessen content of phytic acid in rice, peanut, soybean, sunflower and pigeon pea seeds but it does not enhance availability of nutrients as expected (Mahesh *et al*., 2015; Kumar *et al*., 2010).

Malnutrition has been a serious problem of man since ages. About 870 million of world population are undernourished which made 13% of total population of the globe (WHO, 2014). This phenomenon has deteriorated quality of human life and its work quality badly in the recent years as well (White and Brown, 2010). Need of micronutrients is not very high, still a big ratio of women and children are suffering from its deficiency (Ramakrishna *et al*., 2006). Other than soil fertility status, phytate is a potential anti-nutritional factor which decreases the bioavailability of micro-nutrients (Shi *et al*., 2003).

Noulas *et al*. (2018) describes effective purpose of zinc in plant as in photosynthesis, membrane structure, protein synthesis and disease and drought tolerance. Though it is micronutrient still, its deficiency can cause challenging environment to market value of various crops. There is ever increasing need of extra food due to population explosion and role of zinc in this regard cannot be neglected. Sandy, saline and calcareous soils are reported to be zinc deficient and agricultural products taken from them do not satisfy human need of zinc for proper body functioning. Broadley *et al*. (2007) endorses essentiality of zinc as a nutrient for growth of plants as it is part of many proteins in plants. Essentiality of zinc has been proven in maize, barley and sunflower in start of 20th century, as its deficiency causes many warning signs during plant life. Zinc deficit is very prevalent in high pH soils (Shahid *et al*., 2016). Kaya *et al*. (2009) described that zinc application in soil gave a boost to zinc content in seed of chickpea. It also had a negative relation with PA and seed P. Proportion of high phytate food determines the bio-availability of Zinc in cereals and legumes. High ratios of phytate: zinc i.e., 15:1 provides less zinc (<15%) (Allen et al., 2006).

Rice (*Oryza sativa* L.) holds a position of main staple diet of about half population of the globe. Rice contriutes 21% and 15% per capita of dietary energy and protein. Rice is sensitive to zinc deficiency, and zinc is a vital micronutrient limiting rice production in term of quality and quantity (Yadi *et al*., 2012). Rice is significant food crop in Pakistan after wheat. It is an important cash crop after cotton in terms of export (Pakistan Economic Survey, 2017-18). Keeping in view the said scenario, this experiment was performed

Links Researchers

to observe prospective use of phosphorus and zinc at tillering and booting stages of rice.

Materials and Methods

Site description

This experiment was executed at Soil Chemistry Section, ISCES, AARI, Faisalabad, Punjab, Pakistan. Faisalabad is located at 185.6 meters above sea level. Faisalabad's climate is semi-arid, summer is hot and humid and winter is dry and cool. The temperatures average from 40.5°C to 26.9°C in June and 19.4°C to 4.1°C in January. Annual rainfall averages approximately at 375 millimetres and highly seasonal (Agromet Bulletin, 2017). The soil of experiment is mainly sandy clay loam having pH 8.3, EC 1.26 dSm^{-1}, organic carbon 3.7g kg^{-1}, organic matter 0.70%, available P 8.3 mg kg^{-1} and available potash 200 mg kg^{-1} at surface soil (0-15 cm) while subsurface soil contained 8.1 pH, 1.20 dSm^{-1} EC, 3.4g kg^{-1} organic carbon, 0.67% organic matter, 8.1 mg kg^{-1} available P and 186 mg kg^{-1} available potash (Table 1). Weather data for experimental season is given in Figure 1.

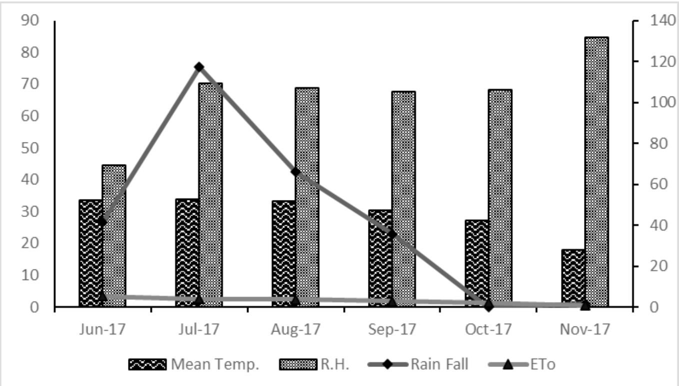

Figure 1: *Mean temperature, relative humidity, rainfall and evapotranspiration for growing season of rice.*

Soil characteristics

Experiment design: Seven treatments were employed with three repeats by using split plot statistical model in a permanent layout setup.

The plot size was 5m*7m (35m^2). Rice was studied at two growth stages i.e., tillering and booting. Growth stages were allotted in main plots while treatments were allotted in sub plots.

Approved dose of NPK viz. 150-90-60 kg ha^{-1} was applied according to treatment plan using Urea (in two splits), diammonium phosphate and sulphate of potash as basal dose. 1st half of Nitrogen was added as basal and second dose was applied at panicle initiation stage. Zn was applied at active tillering and booting stage.

Cultivation technology

Rice seedlings were collected from nursery, already grown at farm area of soil chemistry section forty-five days ago, transplanting was done in mid-July. Rice transplanting was done manually in standing water. Cultivation practices were done when required. Rice was harvested in start of November.

Rice sampling and analysis

When the rice plants had reached at maturity, rice plants were harvested. Later, its grain and straw were weighed. Rice grain were dried in air circulating oven at 60°C and crushed with grinding machine and preserved in polythene bags for later use. Paddy samples were analyzed for P, Zn, total phytin, fiber and protein content.

Table 1: *Initial soil physico-chemical properties.*

Soil property	Units	Depth (cm)	
		0-15	15-30
OC	g kg^{-1}	3.7	3.4
EC	dS m^{-1}	1.26	1.20
pH	-	8.3	8.1
OM	%	0.70	0.67
Available P	mg kg^{-1}	8.3	8.1
Available K	mg kg^{-1}	200	186

Table 2: *Description of experimental treatments.*

Treatment
T_1: Control (RD NPK)
T_2: RD NK+ P @ 60 kg ha^{-1} + Zn@ 5 kg ha^{-1}
T_3: RD NK+ P @ 90 kg ha^{-1} + Zn @ 5 kg ha^{-1}
T_4: RD NK+ P @ 120 kg ha^{-1} + Zn @ 5 kg ha^{-1}
T_5: RD NK+ P @ 60 kg ha^{-1} + Zn @ 10 kg ha^{-1}
T_6: RD NK+ P @ 90 kg ha^{-1} + Zn @ 10 kg ha^{-1}
T_7: RD NK+ P @ 120 kg ha^{-1} + Zn @ 10 kg ha^{-1}

Soil sampling and analysis

Soil samples were taken (0-30 cm) at sowing and harvesting, which were later air dried, grinded and sieved (2mm Sieve) before the further use (Carter, 1993). Soil Texture was determined by Gee and Bauder (1982) method while chemical properties EC and pH was determined using method by (Page *et al.*, 1982). Soil organic carbon was analysed by

Potassium Dichromate Method (Walkley, 1947), soil available P and K extraction was done with 0.5 M $NaHCO_3$ (Olsen P blue method) and 1 N NH_4OAc, respectively.

Statistical analysis

The data collected was subject to ANOVA using split plot design with three replications. Mean comparison was employed according to LSD test ($P \leq 0.05$). All the statistical analysis was carried out by Statistical 8.1 software (Steel *et al*., 1997).

Results and Discussions

Growth attributes of rice

The data regarding the impact of Zn and P on rice growth parameters is given in Table 3. Greater plant height found in plot receiving P @ 90 kg ha^{-1} as basal fertilizer and 5 kg ha^{-1} Zn at booting stage while control gave minimum plant height. Same pattern was observed in other growth attributes i.e., number (no.) of tillers and no. of grains per panicle. Zinc application along with NPK fertilizer, as compared to NPK fertilizer alone, enhanced no. of productive tillers, plant height and filled grains per panicle likewise panicle length and 1000 grain weight also observed the same trend (Rahman *et al*., 2011; Sudha and Stalin, 2015).

Yield attributes of rice

The application of phosphorus and zinc have significant impact at booting and active tillering stage of rice. Results revealed that maximum paddy yield i.e., 4.80 tonns ha^{-1} was found where Zn @ 5 kg ha^{-1} and P @ 120 kg ha^{-1} were used in comparison to control plot. Second higher yield of paddy (4.75 tonns ha^{-1}) was found from treatment receiving phosphorus (120 kg ha^{-1}) along-with Zn (10 kg ha^{-1}) as illustrated in Figure 2. Maximum paddy yield was obtained at booting stage of zinc application. In case of biomass, maximum biomass was attained where P and Zn was used @ 90 kg ha^{-1} and 5 kg ha^{-1} which is not significantly different in two growth stages i.e., tillering and booting as it was 15.83 and 16.14 tons/ hac respectively as illustrated in Figure 3.

Higher yield was attained due to better plant morphology and health i.e., more no. of tillers per plant, heavy seeds and more number of grain panicles. Phosphorus application boost grain yield of rice and its interaction with zinc has a significant effect on rice yield as it is clear from the results (Rahman *et al*., 2011). Phattarakul *et al.* (2009) gave the same finding, Zinc along with Nitrogen enhance rice yield by 12-25%. Similarly, increase in rice biomass may be due to Zn application that increase the straw yield and its interaction with P increased straw yield as reported by Hossain et al. (2009). P fertilization have a tendency to enhance grain and straw yield, and, finally total P in plant tissues (Bindraban *et al*., 2020). Likewise, Zn application concurrently increased crop production and grain Zn concentration under soil conditions supporting low Zn content (Drissi *et al*., 2015; Dimkpa *et al*., 2019).

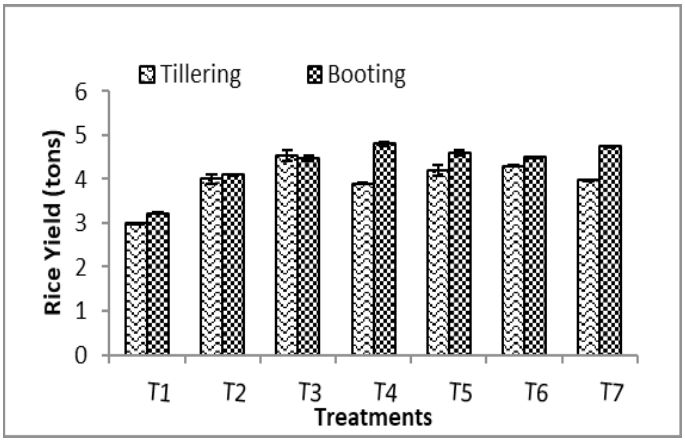

Figure 2: *Impact of P and Zn application on rice yield.*

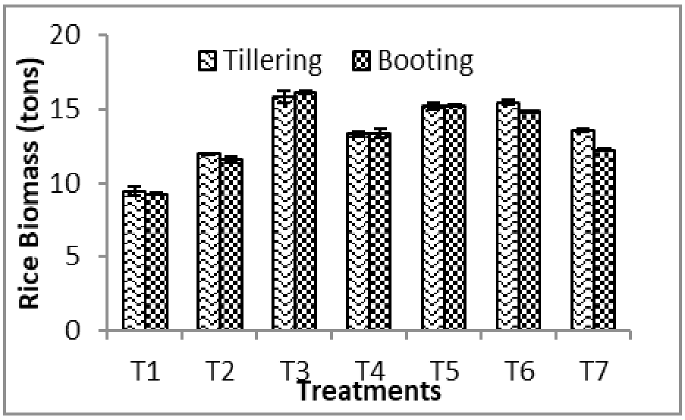

Figure 3: *Impact of P and Zn application on rice biomass.*

Phytic acid content

Zinc fertilizer application has increased the phytic acid content in rice plant. Figure 4 clearly shows, control plant which had no zinc fertilizer has minimum amount of phytic acid, rest of all treatments had higher concentration of phytic acid, minimum phytic acid was found in T_3 i.e., RD NK+ P @ 90 kg/ha as basal dose and Zn @ 5 kg ha^{-1} at tillering stage (1.11%) it was non-significant with control plot (1.12%).

Links Researchers

Table 3: *Impact of P and Zn use on plant growth attributes of rice crop.*

Treatments	Plant height (cm)		No. of tillers		No of grains/panicle	
	Tillering	Booting	Tillering	Booting	Tillering	Booting
T_1	122.00 K	126.67 J	14 E	13 E	133 H	139 G
T_2	147.67 C	137.67 H	17 BCD	19 ABC	156 E	156 DE
T_3	149.33 B	147.00 C	20 AB	20 ABC	163 B	161 BC
T_4	141.33 FG	151.00 A	16 DE	21 A	152 F	163 B
T_5	140.00 G	142.67 EF	17 BCD	19 ABC	159 CD	159 C
T_6	144.00 DE	144.67 D	18 BCD	17 BCD	159 C	163 B
T_7	133.33 I	147.33 C	14 E	17 CD	151 F	166 A
	139.52 B	142.43 A	17 B	18 A	153 B	158 A

Means sharing different alphabets are statistically different ($p<0.05$) using the LSD test.

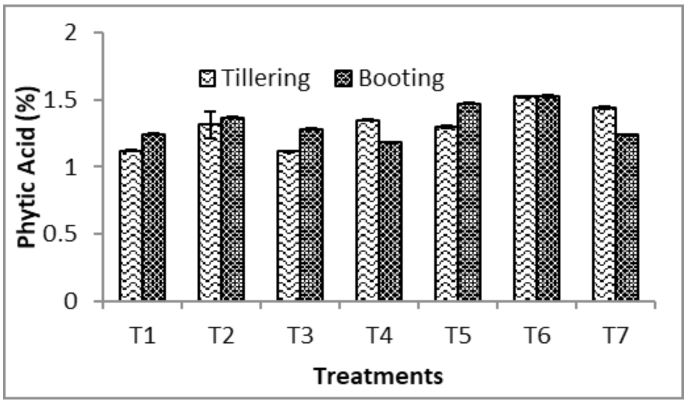

Figure 4: *Impact of P and Zn application on rice grain phytic acid (%).*

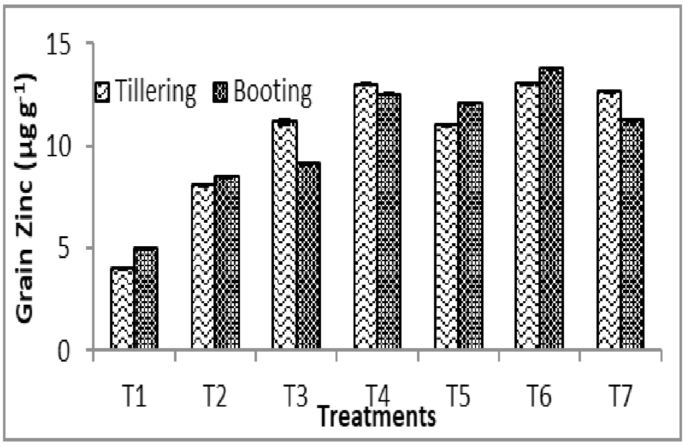

Figure 5: *Impact of P and Zn application on rice grain zinc (µg g^{-1}).*

Kaya *et al.* (2009) wrote that zinc fertilizer application is antagonistically related to phytic acid and seed phosphorus. While study of Wang *et al.* (2011) clarified that phytic acid is mostly present in outer layer of rice kernel, instead of grain. They also found that bran layer has comparatively low concentration of PA as that of other mineral nutrients as Fe, Mn and Mg.

Mineral bioavailability

Phosphorus content (0.55 %) in rice grain was present in treatment receiving P (90 kg ha^{-1} and 120 kg ha^{-1}) respectively and Zn (10 kg ha^{-1}) at booting stage, as compared to control treatment (0.28%) as illustrated in Figure 5. These results are strengthened by Rehim *et al.* (2014) and Amanullah et al. (2020).

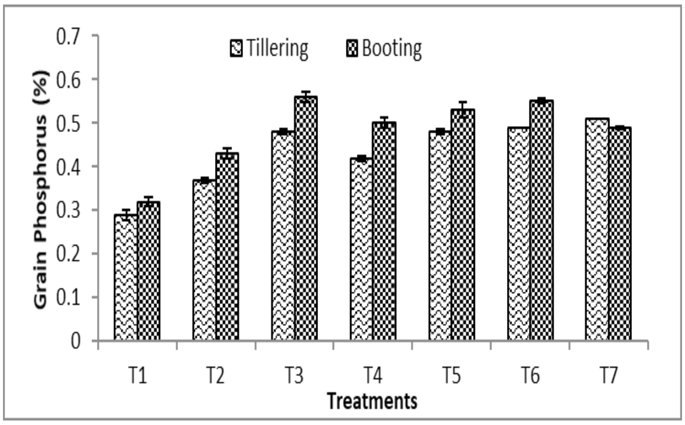

Figure 6: *Impact of P and Zn application on rice grain phosphorus (%).*

Figure 6 depicts that in case of zinc, highest zinc content (13.83 mg kg^{-1}) accumulated in rice grain was found in treatment receiving 90 kg ha^{-1} P and 10 kg ha^{-1} Zn fertilizer (Zhang et al., 2017). Antagonistic correlation of P fertilizer application on Zn, Ca and Fe concentrations is accompanied with more phytate content which deteriorates dietary value of agricultural products (Bindraban *et al.*, 2020). Soil zinc supplement enhanced zinc content in rice plant. (Fang *et al.*, 2008; Ghoneim, 2016), but Phattarakul *et al.* (2009) reported that zinc foliar application was more beneficial in enhancing grain zinc content, because most of soil applied zinc is accumulated in straw and did not reach the grain.

Interaction between phosphorus and zinc in rice

Phosphorus and zinc interaction showed that zinc content increased with increasing Phosphorus

Links Researchers

concentration in grain at tillering as shown in Figure 7. In booting stage, direct relationship was seen between and Zn in rice grain, it may be due to increasing dose of P and Zn fertilizer as shown in Figure 8. The same was confirmed by Amanullah et al. (2020) in their study, they found that increasing P and Zn maximise Zn content in grain, while absence of Zn in applied fertilizer has reduced its content in rice grain (Gianquinto *et al*., 2000).

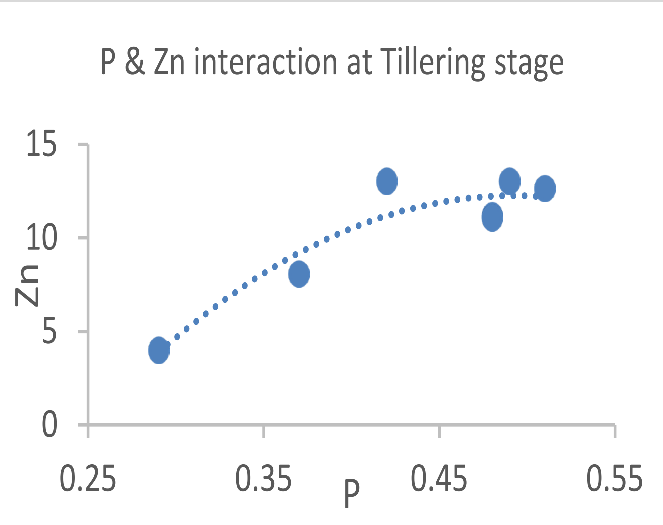

Figure 7: *P and Zn interaction at tillering stage.*

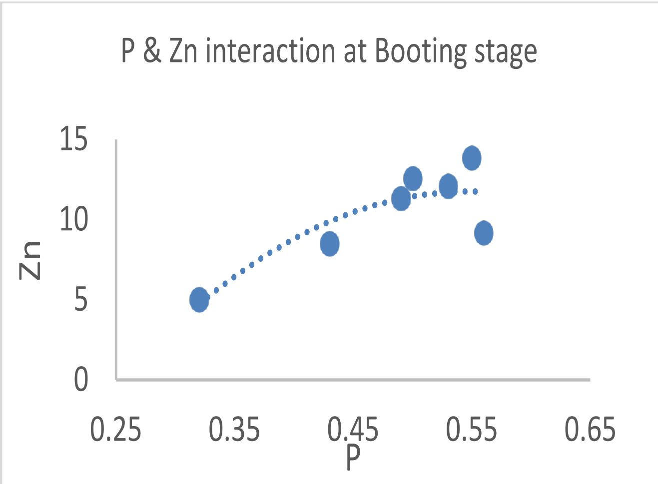

Figure 8: *P and Zn interaction at booting stage.*

Interaction between phosphorus and phytic acid in rice

P × phytic acid interaction revealed that an increase in P level directly influenced Phytic acid content in grains at both growth stages under study i.e. tillering and booting stage of rice as illustrated in Figures 9 and 10.

Interaction between zinc and phytic acid in rice

Interaction between Zn and phytic acid has shown a clear polynomial trendline which depicts that increase in zinc increases PA content in rice grain as shown in Figures 11 and 12.

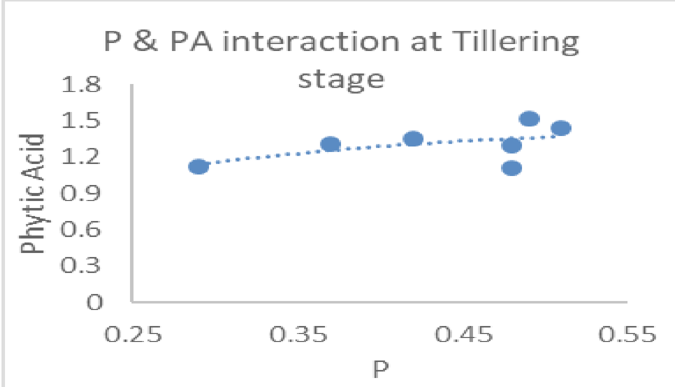

Figure 9: *P and PA interaction at tillering stage.*

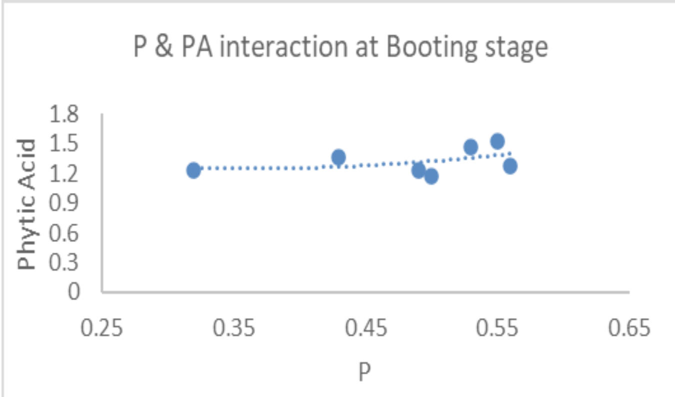

Figure 10: *P and PA interaction at booting stage.*

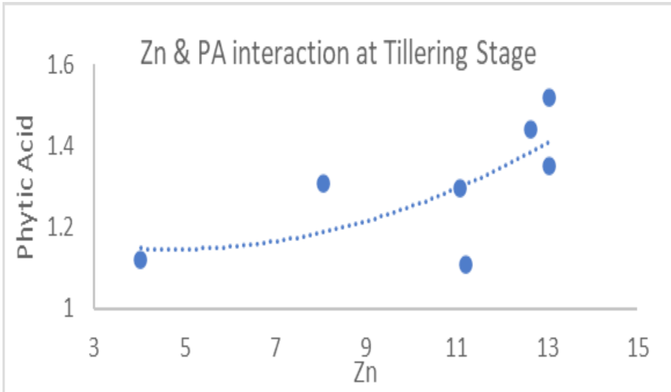

Figure 11: *Zn and PA interaction at tillering stage.*

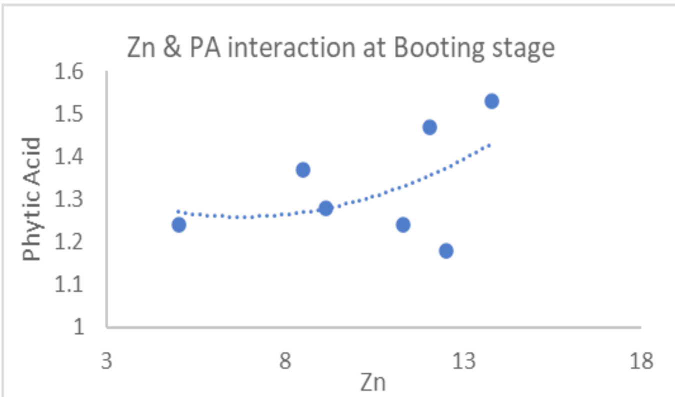

Figure 12: *Zn and PA interaction at booting stage.*

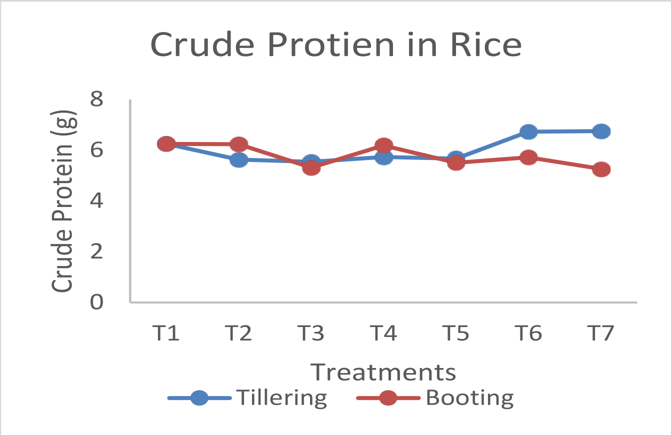

Figure 13: *Impact of P and Zn application on rice crude protein (g).*

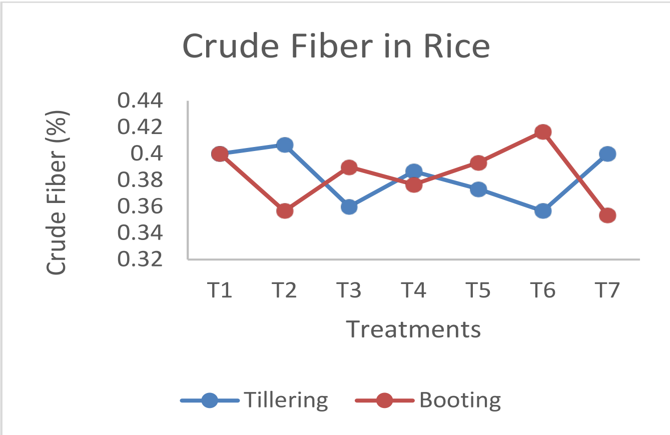

Figure 14: *Impact of P and Zn application on rice crude fiber (%).*

Quality attributes of rice

Crude protein in rice has shown a random effect by zinc application at both stages i.e., tillering and booting stage of rice, as shown in Figure 13. Maximum crude protein detected in T_6 and T_7 (6.73 and 6.75 g, respectively) when zinc was applied at tillering stage as compared to control where it shows 6.25 g. Random crude fibre in rice has been observed with more strength in response to zinc application in above mentioned stages as shown in Figure 14. Maximum crude fibre has been reported in T6 at booting stage i.e., 0.42% as compared to 0.40 % of control. Crude fibre concentration is usually low in polished rice (Eggum, 1979). In quality parameters crude protein significantly increased by the Zn application as compared to NPK alone (Sudha and Stalin, 2015).

Conclusions and Recommendations

This study clearly depicts positive interaction of P and Zn on rice growth, yield and nutrient attributes. Zinc applied at panicle initiation stage showed significantly better results in most of the parameters.

Novelty Statement

There is positive interaction between P and Zn when applied to rice.

Author's Contribution

Farah Rasheed: Concept and designing of work, execution of study and manuscript write up.
Ana Aslam: Data interpretation and graphical representation.
Muhammad Aftab and Ghulam Sarwar: Final editing and proof reading
Raheela Naz and Hina Nazir: Statistical analysis of data
Sadia Sultana and Amina Kalsom: Helped in lab. work
Nisa Mukhtar and Ifra Saleem: Elaborated results and discussion
Qudsia Nazir, Adnan Rafique and Muhammad Arfan-ul-Haq: Worked on materials and methods
Abid Niaz and Muhammad Arif: Participated in introduction portion
Aamer Sattar and Sarfraz Hussain: Overall supervision and guidance about manuscript write up.

Conflict of interest

The authors have declared no conflict of interest.

References

Agromet Bulletin, 2017. Agricultural meteorology cell. Department of Agronomy. University of Agriculture, Faisalabad.

Ali, F., A. Sadiq, I. Ali, M. Amin and M. Amir. 2014. Effect of applied phosphorus on the availability of micronutrients in alkaline-calcareous soil. Environ. *Earth* Sci., 4(15): 143-147.

Allen, L. ed., 2006. Guidelines on food fortification with micronutrients (Vol. 126). Geneva: World Health Organization.

Alwahibi, M.S., M.S. Elshikh, J. Alkahtani, A. Muhammad, S. Khalid, M. Ahmad, N. Khan, S. Ullah and I. Ali. 2020. Phosphorus and zinc fertilization improve zinc biofortification in grains and straw of coarse vs. fine rice genotypes. Agronomy, 10(8): 1155. https://doi.org/10.3390/agronomy10081155

Amanullah, Inamullah, M.S. Alwahibi, M.S. Elshikh, J. Alkahtani, A. Muhammad, S. Khalid, Imran, M. Ahmad, N. Khan,S. Ullah and I. Ali. 2020. Phosphorus and Zinc Fertilization Improve Zinc Biofortification in Grains and Straw of Coarse vs. Fine Rice Genotypes. Agronomy, 10, 1155. https://doi.org/10.3390/agronomy10081155

Bindraban, P.S., C.O. Dimkpa and P. Renu. 2020. Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. Biol. Fertil. Soils, 56: 299–317. https://doi.org/10.1007/s00374-019-01430-2

Blake, G.R. and K.H. Hartge. 1986. Bulk density. In: Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. American Society of Agronomy, Madison, WI, USA.

Broadley, M.R., P.J. White, J.P. Hammond, I. Zelko and A. Lux. 2007. Zinc in plants. New Phytol., 173(4): 677-702. https://doi.org/10.1111/j.1469-8137.2007.01996.x

Carter, M.R., 1993. Soil sampling and methods of analysis. Canadian society of soil science. Lewis Publishers, Boca Raton, Florida, pp. 823.

Dary, O., and R. Hurrell. 2006. Guidelines on food fortification with micronutrients. World Health Organization, Food and Agricultural Organization of the United Nations: Geneva, Switzerland, pp. 3-37.

Dersjant-Li, Y., A. Awati, H. Schulze and G. Partridge. 2015. Phytase in non-ruminant animal nutrition: A critical review on phytase activities in the gastrointestinal tract and influencing factors. J. Sci. Food Agric., 95(5): 878-896. https://doi.org/10.1002/jsfa.6998

Dimkpa, C.O., U. Singh, P.S. Bindraban, I.O. Adisa, W.H. Elmer, J.L. Gardea Torresdey and J.C. White. 2019. Addition-omission of zinc, copper, and boron nano and bulk particles demonstrate element and size specific response of soybean to micronutrients exposure. Sci. Total Environ., 665: 606–616. https://doi.org/10.1016/j.scitotenv.2019.02.142

Drissi, S., A. AïtHoussa, A. Bamouh, J.M. Coquant and M. Benbella. 2015. Effect of zinc-phosphorus interaction on corn silage grown on sandy soil. Agriculture, 5: 1047–1059. https://doi.org/10.3390/agriculture5041047

Eggum, B.O. 1979. The nutritional value of rice in comparison with other cereals. In Proceedings of workshop on chemical aspects of rice grain quality (pp. 91-111).

Erdal, I., A. Yilmaz, S. Taban, S. Eker, B. Torun and I. Cakmak. 2002. Phytic acid and phosphorus concentrations in seeds of wheat cultivars grown with and without zinc fertilization. J. Plant Nutr., 25(1): 113-127. https://doi.org/10.1081/PLN-100108784

Fang, Y., L. Wang, Z. Xin, L. Zhao, X. An, and Q. Hu. 2008. Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in China. J. Agric. Food Chem., 56(6): 2079-2084. https://doi.org/10.1021/jf800150z

FAO, 2018. Global food composition database for phytate version 1.0. Phys. Food Comp., 1.0. Rome, Italy.

Gallaher, D.D., 2012. Potential health benefits of wild rice and wild rice products: Literature (Doctoral dissertation, Karlsruhe Institute of Technology).

García-Estepa, R.M., E. Guerra-Hernández and B. García-Villanova. 1999. Phytic acid content in milled cereal products and breads. Int. Food Res.J., 32(3): 217-221. https://doi.org/10.1016/S0963-9969(99)00092-7

Gee, G.W. and J.W. Bauder. 1982. Hydrometer method. In: A. Klute, (eds.), Methods of soil analysis. Part I. Am. Soc. Agron. No. 9. Madison, WI, USA. pp. 383-411.

Ghoneim, A.M., 2016. Effect of different methods of Zn application on rice growth, yield and nutrients dynamics in plant and soil. J. Agric. Ecol. Res. Int., 6(2): 1-9. https://doi.org/10.9734/JAERI/2016/22607

Gianquinto, G., A. Abu-Rayyan, L. Di-Tola, D. Piccotino and B. Pezzarossa. 2000. Interaction effects of phosphorus and zinc on photosynthesis, growth and yield of dwarf bean grown in two environments. Plant Soil, 220(1): 219–228. https://doi.org/10.1023/A:1004705008101

Global Nutrition Report, 2016. From promise to impact: Ending malnutrition by 2030. International Food Policy Research Institute, Washington, DC. https://doi.org/10.2499/9780896295841

Hossain, M.B., M. Jahiruddin, R.H. Loeppert, G.M. Panaullah, M.R. Islam and J.M. Duxbury. 2009. The effects of iron plaque and phosphorus on yield and arsenic accumulation in rice. J. Plant Soil, 317: 167-176.

IFPRI, 2016. International Food Policy Research Institute. 2016. Global Nutrition Report 2016:

From Promise to Impact: Ending Malnutrition by 2030. Washington, D.C.

Kaya, M., Z. Küçükyumuk and I. Erdal. 2009. Phytase activity, phytic acid, zinc, phosphorus and protein contents in different chickpea genotypes in relation to nitrogen and zinc fertilization. Afr. J. Biotechnol., 8(18): 4508–4513.

Kumar, V., K.A. Sinha, H.P.S. Makkar and K. Becker. 2010. Dietary roles of phytate and phytase in human nutrition: A review. Food Chem., 120: 945–959. https://doi.org/10.1016/j.foodchem.2009.11.052

Larson, S.R., J.N. Rutger, K.A. Young and V. Raboy. 2000. Isolation and genetic mapping of a non-lethal rice (*Oryza sativa* L.) low phytic acid 1 mutation. Crop Sci., 40(5): 1397-1405. https://doi.org/10.2135/cropsci2000.4051397x

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J., 42: 421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Mahesh, S., G.J. Pavithra, M.S. Parvathi, R. Rajashekara and A.G. Shankar. 2015. Effect of processing on phytic acid content and nutrient availability in food grains. Int. J. Agric. Sci., 5: 771-777.

Mate, H., and L. Radomir. 2002. Phytic acid content of cereals and legumes and interaction with proteins. Period. Polytech. Ser. Chem. Eng., 46(1-2): 59-64.

Mclean, E.O., 1982. Soil pH and lime requirement. In: Methods of soil analysis, part 2: Chemical and microbiological properties (eds. A.L. Page, R.H. Miller and D.R. Keeney). Am. Soc. Agron. Madison, WI, USA 1982; pp. 199-209.

Nissar, J., T. Ahad, H.R. Naik and S.Z. Hussain. 2017. A review phytic acid: As antinutrient or nutraceutical. J. Pharmacogn. Phytochem., 6(6): 1554-1560.

Noulas, C., M. Tziouvalekas and T. Karyotis. 2018. Zinc in soils, water and food crops. J. Trace Elem. Med. Biol., 49: 252-260. https://doi.org/10.1016/j.jtemb.2018.02.009

Page, A., R. Miller and D. Keeney. 1982. Methods of soil analysis; chemical and microbiological properties, Soil Sci. Soc. Am. Madison, W.I., 2.

Pakistan Economic Survey, 2017-2018. Highlights of Pakistan economic survey report 2017-2018. Section agriculture. Ministry of Finance, Govt of Pakistan. pp.17.

Perera, I., A. Fukushima, T. Akabane, G. Horiguchi, S. Seneweera and N. Hirotsu. 2019. Expression regulation of myo-inositol 3-phosphate synthase 1 (INO1) in determination of phytic acid accumulation in rice grain. Sci. Rep., 9(1): 1-11. https://doi.org/10.1038/s41598-019-51485-2

Perera, I., S. Seneweera and N. Hirotsu. 2018. Manipulating the phytic acid content of rice grain toward improving micronutrient bioavailability. Rice, 11(1): 1-13. https://doi.org/10.1186/s12284-018-0200-y

Phattarakul, N., I. Cakmak, and P. Boonchuay. 2009. Role of zinc fertilizers in increasing grain zinc concentration and improving grain yield of rice. UC Davis The Proceedings of the International Plant Nutrition Colloquium XVI.

Raboy, V., P.F. Gerbasi, K.A. Young, S.D. Stoneberg, S.G. Pickett, A.T., Bauman and D.S. Ertl. 2000. Origin and seed phenotype of maize low phytic acid 1-1 and low phytic acid 2-1. Plant Physiol., 124(1): 355-368. https://doi.org/10.1104/pp.124.1.355

Rahman, K.M., M.A.K. Chowdhury, F. Sharmeen, A. Sarkar, M.A., Hye, G.C. Biswas and Sarkar, A., 2011. Effect of zinc and phosphorus on yield of *Oryza sativa* (cv. br-11). Bangladesh Res. Publ. J., 5: 351-358.

Ramakrishna, V., P.J. Rani and P.R. Rao. 2006. Anti-nutritional factors during germination in Indian bean (*Dolichos lablab* L.) seeds. World J. Dairy Food Sci., 1(1): 6-11.

Rehim, A., M. Zafar-ul-Hye, M. Imran, M.A. Ali, and M. Hussain. 2014. Phosphorus and zinc application improves rice productivity. Pak. J. Sci., 66(2): 134-139.

Ryan, J., G. Estefan and A. Rashid. 2001. Soil and plant analysis laboratory manual. ICARDA. Alleppo, Syria.

Shahid, M., A.K. Shukla, P. Bhattacharyya, R. Tripathi, S. Mohanty, A. Kumar, B. Lal, P. Gautam, R. Raja, B.B. Panda, B. Das and A.K. Nayak. 2016. Micronutrients (Fe, Mn, Zn and Cu) balance under long-term application of fertilizer and manure in a tropical rice-rice system. J. Soils Sediments, 16(3): 737-747. https://doi.org/10.1007/s11368-015-1272-6

Shi, J., H. Wang, Y. Wu, J. Hazebroek, R.B. Meeley and D.S. Ertl. 2003. The maize low-phytic acid mutant lpa2 is caused by mutation in an inositol phosphate kinase gene. Plant Physiol., 131(2): 507-515. https://doi.org/10.1104/pp.014258

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and procedures of statistics. Mc Graw Hill Co. Inc. New York.

Sudha, S., and P. Stalin. 2015. Effect of zinc on yield, quality and grain zinc content of rice genotypes. Int. J. Farm Sci., 5(3): 17-27.

Walkley, A., 1947. A critical examination of a rapid method for determining soil organic carbon in soils. Effect of variations in digestion conditions and inorganic soil constituents. J. Soil Sci., 63: 251-263. https://doi.org/10.1097/00010694-194704000-00001

Wang, K.M., J.G. Wu, G. Li, D.P. Zhang, Z.W. Yang and C.H. Shi. 2011. Distribution of phytic acid and mineral elements in three indica rice (*Oryza sativa* L.) cultivars. J. Cereal Sci., 54(1): 116–121. https://doi.org/10.1016/j.jcs.2011.03.002

White P.J. and P.H. Brown. 2010. Plant nutrition for sustainable development and global health. Ann. Bot., 105: 1073–1080. https://doi.org/10.1093/aob/mcq085

WHO, 2014. Undernourishment around the world in 2012. (Accessed on 24th April, 2014) http://www.fao.org/docrep/016/i3027e/i3027e02.pdf

Xie, X., R. Li, Y. Zhang, S. Shen and Y. Bao. 2018. Effect of elevated [CO_2] on assimilation, allocation of nitrogen and phosphorus by maize (*Zea mays* L.). Commun. Soil Sci. Plant Anal., 49: 1032–1044. https://doi.org/10.1080/00103624.2018.1448413

Yadi, R., S. Dastan and E. Yasari. 2012. Role of zinc fertilizer on grain yield and some qualities parameters in Iranian rice genotypes. Ann. Biol. Res., 3(9): 4519-4527.

Zhang, W., D. Liu, Y. Liu, X. Chen and C. Zou. 2017. Overuse of phosphorus fertilizer reduces the grain and flour protein contents and zinc bioavailability of winter wheat (*Triticum aestivum* L.). J. Agric. Food. Chem., 65:1473–1482.