Research Article

Growth and Yield of Lentil (*Lens Esculenta* L.) Influenced by Zn Application with PGPR Inoculation under Rain-Fed Conditions

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Abstract | A field experiment on lentil was conducted to see the effect of Zn application alongwith PGPR on growth and yield under rain-fed conditions at National Agricultural Research Centre (NARC), Islamabad during 2016-17. Split plot design (main plots with and without inoculation and Zn application in sub-plots) with three replications was followed. Agronomic data i.e., plant height, pods per peduncle, seeds per pod, 100-seed weight, total biomass and grain yield were recorded. Plant samples were collected at maturity to determine Zn concentration in plant tissues and grains. A significant increase in pods per peduncle, seeds per pod, grain yield and total biomass of lentil was observed with Zn application even at lower rate (5 kg ha^{-1}) under PGPR inoculation. Maximum 100-seed weight (2.56 g) was recorded with PGPR inoculation which was 21 % higher than that of without PGPR inoculation. Overall, a significant increase (31 %) in grain yield and total biomass was observed due to Zn application as well as PGPR inoculation. Similarly, maximum Zn concentration in plant tissues and its uptake (kg ha^{-1}) was determined from the treatments where Zn was applied under PGPR inoculation.

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Introduction

Lentil is the second major winter season delicious food legume after chickpea in Pakistan. It is mainly grown in all the provinces but the $^{2}/_{3}{}^{rd}$ area is in Punjab. The area as well as its production has been decreased gradually mainly due to shift of main lentil area to other crops, weed and disease problems, and non-availability of certified and quality seed of improved varieties (Anonymous, 2015). So far, micronutrient constraints are the consequence of peculiar soil properties. Free $CaCO_3$ dominates the chemistry of these soils: $CaCO_3$ fixes micronutrient cations; alkaline pH reduces their solubility and low organic matter limits micronutrient replenishment to soil solution (Tandon, 1995; Cakmak, 1998). In comparison to major nutrient deficiencies, however, micronutrient problems are highly location-specific. Soil micronutrient deficiencies not only reduce crop productivity, but also low micronutrient concentrations in plant food adversely affect human health and well-being. Zinc is an essential micronutrient required for optimum crop growth. Globally, Zn deficiency is the most important micronutrient problem, particularly in alkaline calcareous soils. Factors which induce Zn deficiency include alkaline soil pH, soil calcareousness, low soil organic matter, exposed subsoil (eroded or leveled), sandy texture, Zn-free fertilizers, accentuated Zn mining by high-yielding varieties, and/or flooding-induced electro-chemical changes. The soil of different part of Pakistan is more or less deficient in Zn as well as N fixing Bacteria (*Rhizobium* sp.) which are main cause of poor yield. However, there is a great possibility to increase lentil production by cultivating even on marginal lands with balanced fertilization including micronutrient. Micronutrients play an important role in increasing yield of pulses through their effect on the plant itself and on the N fixing by symbiotic process. Deficiencies of these nutrients have been very pronounced under multiple cropping systems due to excessive removal by the crops. Zinc deficiency is widespread in the country; much observed in wetland rice soils, light textured and calcareous soils (Jahiruddin et al., 1992; Rahman et al., 1993; Islam et al., 1997; Quddus et al., 2014). Poor growth, interveinal chlorosis and necrosis of lower leaves are the common symptoms of Zn deficiency in field crops. Plants emerged from seeds with low concentrations of Zn could be highly sensitive to biotic and abiotic stresses (Obata et al., 1999). Zinc enriched seeds can perform better with respect to seed germination, seedling health, crop growth and finally yield advantage (Cakmak et al., 1996; Abdo, 2001). PGPRs are reported to enhance crop growth and yields through increased nutrient availability due to acidifying the rhizosphere (Aslam et al., 2000; Bais et al., 2006; Pothier et al., 2007; Badri et al., 2009; Shukla et al., 2011; Drogue et al., 2013). Rhizobium inoculation, phosphorus, zinc, and optimum seed rate are proved to be highly economical inputs for maximizing lentil production. High and effective nodulation on the roots of the lentils is an important agronomic factor for enhanced productivity and fixation of atmospheric nitrogen into the soil. Therefore, the present study was planned to investigate adequate Zn application along with PGPR to increase lentil productivity.

Materials and Methods

A field experiment was conducted to investigate adequate Zn application along with PGPR to increase lentil productivity under rain-fed condition at National Agricultural Research Centre, Islamabad during 2016-17. Prior to sowing a random soil sample was collected to analyze basic physico-chemical properties (NO_3-N, P, K, Zn, pH, OM ECe and soil texture). Treatments applied were Control (No Zn application), 5 and 10 kg Zn ha^{-1} with and without PGPR inoculation. Lentil crop (var. Markiz-09) was grown in split plot design with three replications. Planting methods i.e., with and without PGPR were kept in main plots and various Zn doses (0, 5 and 10 kg Zn ha^{-1}) were applied in sub plots.

Recommended basal dose of NPK @ 30, 60 and 25 kg ha^{-1} as urea, TSP and SOP respectively were applied to all the plots at the time of sowing. Weeding was done manually when required to control weeds and the crop was grown to maturity. Pre-sowing soil samples (0-15 cm depth) were collected for the analysis of general soil characteristics (Table 1) according to the methods suggested by Ryan et al. (2001). Plant samples were collected at maturity for the determination of Zn concentration in plant tissues and grain to calculate its total uptake as:

Total Zn Uptake (mg/ha)= Zn conc. (mg/kg) in plant parts x Yield (kg/ha)

At maturity, the crop was harvested and agronomic data on plant height, pods per peduncle, seed per pod, 100-grain weight, grain yield and total biomass were recorded. The data thus, collected were subjected to statistical analysis using software package MSTAT-C and treatment means were compared using least significant difference (LSD) at 5 % probability level (Gomez and Gomez, 1984).

Results and Discussion

Growth and yield of lentil

Zinc fertilizer application with and without PGPR significantly influenced growth and yield contributing parameter of lentil. A significant increase in total biomass production and grain yield over control was harvested from the plots where Zn was applied along with PGPR whereas the growth and yield were comparably less under no PGPR inoculation. Lack of positive yield response without PGPR might be due to comparatively poor root functioning which resulted in insubstantial plant growth and less seed formation per pod (Table 2).

Others yield contributing characters showed significant variation due to different levels of Zn application. The highest plant height 27.8 cm was recorded with Zn level 3.0 kg/ha which was statistically identical to Zn level 2.0 and 1.0 kg/ha, respectively but significantly higher over control. The maximum number of pods per plant was found with

Table 1: *Physico-chemical analysis of the soils and soil texture at experimental site.*

Parameters	Unit	Values	
		Before Sowing	After Harvest
pH	–	8.70	8.50
ECe	dS m^{-1}	0.41	0.40
$CaCO_3$	%	4.91	4.87
OM	%	0.51	0.52
NO_3-N	%	2.14	2.28
ExtractableP(AB-DTPA)	mg kg^{-1}	2.07	2.11
Extractable K (AB-DTPA)	mg kg^{-1}	84.73	84.79
Zn (ABDTPA)	mg kg^{-1}	1.13	1.26
Sand	%	31.70	31.70
Silt	%	28.29	28.29
Clay	%	40.11	40.11
Textural Class	–	Sandy clay loam	Sandy clay loam

Table 2: *Growth of lentil (Lens esculenta L.) influenced by Zn application and PGPR inoculation under rain-fed conditions. (Average of three Repeats).*

Treatments	Plant Height (cm)		Mean	Pods peduncle^{-1}		Seed pod^{-1}		Mean
	+ PGPR	– PGPR		+ PGPR	– PGPR	+ PGPR	– PGPR	
0 kg Zn ha^{-1}	38.33 a	36.33 c	37.33 ^{NS}	2.67 bc	2.43 c	1.89 ab	1.67 c	2.16 B
5 kg Zn ha^{-1}	38.33 a	37.33 b	37.83	2.86 ab	2.67 bc	1.99 ab	1.78 c	2.33 A
10 kg Zn ha^{-1}	38.67 a	37.67 b	38.17	2.99 a	2.67 bc	2.01 a	1.87 ab	2.34 A
Mean	38.44 ^{NS}	37.11		2.84 ^{NS}	2.59	1.96 ^{NS}	1.77	

Means bearing same letter(s) in each column are statistically similar at $p \leq 0.05$; ^{NS} Means in each column are non-significant.

Zn level 3.0 kg ha^{-1} which was statistically identical with Zn level 2.0 and 1.0 kg ha^{-1} but significant difference was observed with control. The maximum number of seeds per pod was obtained from Zn level 3.0 and 2.0 kg/ha which were statistically identical with the Zn level 1.0 but significantly higher over control. The highest 1000 seed weight 16.03 g was obtained from the treatment Zn level 3.0 kg ha^{-1} which was significantly higher than that of other treatments (Table 2). In this concern, Babaeian et al. (2011) stated that zinc has favorable effects on the metabolism of plant which might be responsible for greater metabolite accumulation in the reproductive organs that significantly influenced the yield contributing characters like plant height, number of pods per plant, number of seeds per pod and 1000-seed weight of lentil. In an other study, Bakry et al. (2012) reported that foliar spray of zinc increases the number of fruiting branches plant and number of seed capsule. This may be due to the involvement of zinc in photosynthesis, for chlorophyll production, pollen function and fertilization (Pandey et al., 2006).

The data in Table (Table 3) showed that overall, maximum 100-seed weight (2.56 g) was recorded with PGPR inoculation which was 21 % higher than that of without PGPR inoculation. Maximum growth and yield of lentil was observed with Zn application even at lower rate (5 kg ha^{-1}) under PGPR inoculation. Overall, a significant increase (31 %) in grain yield and total biomass was observed due to Zn application as well as PGPR inoculation. Similarly, maximum Zn concentration in plant tissues and its uptake (kg ha^{-1}) was determined from the treatments where Zn was applied under PGPR inoculation. The reason might be that PGPR supported rhizosphere providing favorable environment to enhance activity of a huge and diversified microbial community, including microorganisms capable to promote plant growth. Among the latter, plant growth-promoting rhizobacteria (PGPR) colonize roots and enhance plant growth by direct and indirect mechanisms. Modification of root system architecture by PGPR implicates the production of phytohormones and other signals that lead, mostly, to enhanced lateral root branching and development of root hairs owing

Table 3: *Yield of lentil (Lens esculenta L.) influenced by Zn application and PGPR inoculation under rain-fed conditions. (Average of three Repeats).*

Treatments	100 seed weight (g)		Mean	Grain yield (t ha^{-1})		Total biomass (t ha^{-1})		Mean
	+PGPR	−PGPR		+PGPR	−PGPR	+PGPR	−PGPR	
0 kg Zn ha^{-1}	2.12 c	2.04 c	2.08 C	0.86 d	0.54 c	0.70 B	3.58 b	2.83 c
5 kg Zn ha^{-1}	2.58 b	2.40 b	2.49 B	1.08 c	0.89 ab	0.99 A	4.21 a	3.17 c
10 kg Zn ha^{-1}	2.98 a	2.59 b	2.79 A	1.13 bc	0.92 a	1.03 A	4.23 a	3.17 c
Mean	2.56 A	2.11 B		1.02 A	0.78 B		4.01 A	3.06 B

Means bearing same letter(s) in each column are statistically similar at $p \leq 0.05$; NS Means in each column are non-significant.

Table 4: *P and K Concentration in plant tissues of lentil (Lens esculenta L.) influenced by Zn application and PGPR inoculation under rain-fed conditions. (Average of three Repeats).*

Treatments	P (%)		Mean	K (%)		Mean
	+PGPR	−PGPR		+PGPR	−PGPR	
0 kg Zn ha^{-1}	0.25 ^{NS}	0.23	0.24^{NS}	2.13 ^{NS}	1.99	2.06 ^{NS}
5 kg Zn ha^{-1}	0.24	0.22	0.23	2.13	2.13	2.13
10 kg Zn ha^{-1}	0.25	0.22	0.24	2.15	2.15	2.15
Mean	0.25 A	0.22 B		2.14 ^{NS}	2.09	

Means bearing same letter(s) in each column are statistically similar at $p \leq 0.05$; NS Means in each column are non-significant.

Table 5: *Zn Concentration (mg kg^{-1}) in plant tissues and its total uptake (mg ha^{-1}) by lentil (Lens esculenta L.) influenced by Zn application and PGPR inoculation under rain-fed conditions. (Average of three Repeats).*

Treatments	Zn contents in tissues (mg kg^{-1})			Total Zn uptake (mg ha^{-1})		
	+PGPR	−PGPR	Mean	+PGPR	−PGPR	Mean
0 kg Zn ha^{-1}	24.13 b	19.95 c	22.04 B	0.109 b	0.076 cd	0.093 BC
5 kg Zn ha^{-1}	29.95 a	21.63 bc	25.79 A	0.156 a	0.090 bc	0.123 AB
10 kg Zn ha^{-1}	29.83 a	21.71 b	25.74 A	0.157 a	0.091 bc	0.124 AB
Mean	27.97 A	21.16 B		0.142 A	0.086 B	

Means bearing same letter(s) in each column are statistically similar at $p \leq 0.05$; NS Means in each column are non-significant.

$$\textbf{Total Zn Uptake}\left(\frac{\textbf{mg}}{\textbf{ha}}\right) = \frac{\text{Zn content } (mg\ kg^{-1}) \times Total\ yield\ (kg\ ha^{-1})}{100}$$

to maximum nutrient availability. PGPR also modify root functioning, improve plant nutrition and influence the physiology of the whole plant. Similar results have also been reported by Bais et al. (2006) and Almario et al. (2013). Several reports have revealed that PGPR are able to produce ABA or gibberellic acid, or to control the level of these hormones in plants (Ribaudo et al., 2006; Richardson et al., 2009; Dodd et al., 2010). (Table 4, Table 5)

Author's Contribution

Imdad Ali Mahmood: Conceived the idea and overall management of the manuscript.
Muhammad Imran and Muhammad Aqeel Sarwar: Data collection and incoporation.
Muhammad Sarwar: Helped in write-up and references.
Matiullah Khan and Shoaib Ahmed: Helped in soil and plant analysis.
Shahid Riaz Malik: Technical inputs and improvement.

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