

Influence of phosphorus, sulphur and zinc levels on yield, quality and nutrients uptake of lentil (*Lens culinaris*) in sub-humid southern plain of Rajasthan

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ABSTRACT

An experiment was laid out in randomized complete block design (factorial experiment) during the winter (*rabi*) seasons of 2020–21 and 2021–22 at Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur (Rajasthan) to study the effect of P (30, 40 and 50 kg P₂O₅/ha), S (15, 20 and 25 kg S/ha) and zinc (control and foliar spray of 0.5% ZnSO₄) on yield nutrient content and nutrients uptake in lentil. Seed yield increased to a maximum of 9.35% following P application, 9.38% after S application and 4.71% after Zn application. Corresponding increase in haulm yield was 12.90%, 10.64% and 7.30% respectively. Application of P, S and Zn improved protein content in seed as well as in haulms and increasing application level of both P and S maintained the increasing trend in protein content. Application of P, S and Zn increased both the content and the uptake of N, P, K, S and Zn both in seeds and in haulms. In most instances these changes were statistically significant.

Key words: Nutrient uptake, Phosphorus, Quality, Sulphur, Yield, Zinc

Pulses play a crucial role in the establishment of sustainable food systems (Franke *et al.*, 2018). Not only they are rich in nutrients, but they also make a positive impact on soil fertility and agricultural biodiversity. Lentil, a crucial winter crop globally, is becoming popular for its nutritional value especially in vegetarian diets. Lentil yield over the years has increased through improved techniques. Globally, lentils cover 5.01 million hectares, yielding 4.0 million tonnes with a productivity level of 1038 kg/ha. In India, lentil is being grown on an area of about 1.42 million ha with production of 1.28 million tonnes with a productivity level of 904 kg/ha (DPD, 2021).

India's pulse productivity lags behind due to various factors like poor quality seeds, cultivation on marginal lands, and inadequate infrastructure (Choudhary, 2013).

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Despite efforts, farmers face challenges including erratic weather and soil nutrient deficiencies, notably phosphorus, sulphur, and zinc in Rajasthan (Bhattacharjee *et al.*, 2013). Phosphorus deficiency affects pulse growth and root development. The soils found in Rajasthan have a limited availability of phosphorus, ranging from poor to medium, as approximately 30% of the applied phosphorus is accessible for crops, while the rest is converted into insoluble phosphorus (Sharma and Khurana, 1997). To address this, additional phosphorus can be applied to the soil, which aids in the formation of nodules and subsequently increases nitrogen fixation, transduction, macromolecular biosynthesis and respiration. Sulphur plays a crucial role as one of the key plant nutrients, with a growing emphasis on its significance in Indian agriculture (Singh and Nariya, 2017). It is a component of various vital compounds like cysteine, methionine, cystine, coenzymes thioredoxine, and sulfolipids. Legume crops typically have a higher demand for S compared to cereal crops (Singh *et al.*, 2016). Zinc plays a vital role in metabolic reactions, enzyme systems, and RNA synthesis, affecting crop yield and quality. The application of Zn demonstrated a positive effect on both grain yield and seed Zn concentration, especially in Zn-deficient soils as reported by Debata *et al.*, (2022). Foliar applications of fertilizers are one of the ways of using

fertilizers more efficiently and economically (Yadav *et al.*, 2023). Maintaining a balance between phosphorus and zinc is essential for optimal plant growth, with residual effects impacting subsequent crops (Kumawat *et al.*, 2022). Zinc application positively impacts lentil yield and nutrient uptake (Verma *et al.*, 2017). Considering these factors, this study aims to optimize P, S, and Zn application to maximize lentil yield in Sub-Humid Agro environments.

MATERIALS AND METHODS

The experimental study was carried out in the years 2020–21 and 2021–22 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur, situated at 24°35'N latitude, 74°42'E longitude, and an altitude of 581.13 meters above sea level. This area falls within agro-climatic zone IVa (Sub-Humid Southern Plain and Aravali hills) of Rajasthan. The soil in the field was characterized as clay loam with a slightly alkaline pH (8.2). The average maximum and minimum temperatures ranged from 24.5°C–33.7°C and 6.9°C–16.3°C, and 23.8°C–31.4°C and 3.3°C–12.4°C, with relative humidity levels between 56.6–94 and 65.7–94.2% during 2020–21 and 2021–22, respectively. The study was conducted in randomized complete block design (factorial experiment) with 3 replications and 18 treatment combinations. The phosphorus factor consisted of 3 levels: 30, 40, and 50 kg/ha, while the sulphur level also had 3 levels: 15, 20, and 25 kg/ha. The zinc factor had 2 levels: control and 0.5% ZnSO₄ at 55 Days after sowing (DAS). The lentil variety, Kota Masoor-2, was used in the experiment with a seed rate of 60 kg/ha and a row spacing of 30 cm. Prior to sowing, the seeds were inoculated with *Rhizobium leguminosarum*. The entire dose of nitrogen, phosphorus (in the form of DAP), and sulphur (in the form of Gypsum) was applied in the field before sowing the crop. Zinc (in the form of ZnSO₄ neutralized with lime) was applied as a foliar spray at 55 DAS. The crop was subjected to various agronomic practices in accordance with the prescribed package of practices (seed rate- 50-60 kg/ha, recommended dose of fertilizers is NKPS; 20:40:20:20) for the region.

Following the harvest, the grain and haulm yields were measured. The grain and straw samples were digested in a diacid mixture (3:1 of HNO₃: HClO₄) and then analysed for phosphorus using the molybdovanadate yellow color method, potassium using a Flame photometer, and zinc using an atomic absorption spectrophotometer. The nitrogen content in both grain and straw was determined through a modified Kjeldahl's method (Jackson 1973). The estimation of sulphur was conducted using the Turbimetric method (Tabatabai and Bremner, 1970). The uptake of nutrients was calculated based on their concentrations in the grain and straw, as well as the respective crop yields. To

ascertain the protein content as a percentage, the total nitrogen content in the raw materials was multiplied by the conventional conversion factor of 6.25. The statistical analysis of the data obtained from two consecutive years was conducted as per the methodology provided by Gomez and Gomez (1984). ANOVA procedures were used to analyse the standard error of mean (SEm±) and the value of critical difference (CD) at 5% level of significance to compare the difference between the mean values.

RESULTS AND DISCUSSION

Yield

A notable increase in seed and haulm yields was recorded with 50 kg P₂O₅/ha, followed by 40 kg P₂O₅/ha. The lentil seed yield saw increments of 9.35 and 11.51% under 40 and 50 kg P₂O₅/ha, respectively, compared to 30 kg P₂O₅/ha. Similarly, the haulm yield showed corresponding increases of 12.90 and 13.78% (Table 1). Phosphorus plays a crucial role in all biological systems, being involved in numerous metabolic pathways and serving as a vital building block for nucleic acids, coenzymes, phosphoproteins and phospholipids. Consequently, the application of phosphorus has led to remarkable enhancements in both the grain and stover yields of lentil crops. The enhancement in crop yield can be attributed to the increase in various yield attributes, including the number of pods per plant, seeds per pod, test weight, as well as the overall seed and straw yields of lentil crop. This improvement is primarily due to the application of phosphorus, as indicated by studies conducted by Datta *et al.*, (2013) and Singh *et al.*, (2016). Similarly, Khaleeq *et al.*, (2023) and Samim *et al.*, (2023) also reported a significant increase in yield attributes, as well as the production of pods, kernels, haulm, and overall yield of groundnut and mung bean, respectively, with the application of 60 kg P₂O₅/ha.

Achieving a maximum seed yield of 1,790 kg/ha and haulm yield of 3,795 kg/ha, was possible with the application of 25 kg S/ha, which was notably higher than the yields obtained with 15 kg S/ha and 20 kg S/ha. The use of 25 kg S/ha resulted in a 9.38% increase in seed yield and a 10.64% increase in haulm yield compared to 15 kg S/ha. The boost in crop yield can be attributed to the heightened cell multiplication and expansion that occurs throughout the entire growth period. The rise in sulphur availability could have contributed to an amplification in the progression of tissue differentiation from somatic to reproductive, along with the advancement of meristemic activity and the formation of floral primordia. As a result, this could have led to an increased number of flowers and ultimately a higher production of seeds (Chaudhari *et al.*, 2019). There was significant growth in various yield-related parameters, such as the number of primary and secondary branches,

Table 1. Effect of different levels of phosphorus, sulphur and zinc on seed and haulm yields of lentil and protein content (%) in lentil seed (pooled data of 2 years)

Treatment	Seed yield (kg/ha)	Haulm yield (kg/ha)	Protein content in seed (%)
<i>Phosphorus level (kg/ha)</i>			
30	1,605	3,363	15.16
40	1,755	3,797	18.00
50	1,790	3,827	18.87
SEm±	18	41	0.093
CD (P=0.05)	51	115	0.263
<i>Sulphur level (kg/ha)</i>			
15	1,635	3,430	15.51
20	1,725	3,761	17.81
25	1,790	3,795	18.71
SEm±	18	41	0.093
CD (P=0.05)	51	115	0.263
<i>Zinc level</i>			
Control	1,677	3,533	16.90
0.5 % ZnSO ₄	1,756	3,791	17.78
SEm±	15	33	0.076
CD (P=0.05)	42	94	0.215

capsules per plant, seeds per capsule, and test weight (1,000-seed weight) (Yumnam *et al.*, 2018 and Kumawat *et al.*, 2022). This indicates that the application of 25 kg/ha sulphur treatment can lead to a substantial increase in seed production.

Zinc fertilization had a notable effect on the yield of lentils when compared to the control. The application of a foliar spray containing 0.5% ZnSO₄ led to a 4.71% increase in seed yield and a 7.30% increase in haulm yield. Zinc translocation to seeds is heightened during reproductive phases like fertilization and pollen grain formation, resulting in increased yield (Math *et al.*, 2022). The increase in these features is a direct result of zinc's involvement in enzyme activation, maintenance of membrane integrity, formation of chlorophyll, regulation of stomatal balance, and utilization of starch during the early stages (Singh and Bhatt, 2013). It was found by Sharma and Thakral (2023) that foliar fertilization of zinc is a key factor in enhancing seed yield of Indian mustard within the normal range of climatic conditions for its growth.

Protein content

The protein content in lentil seeds showed a steady and notable rise as the levels of P, S, and zinc spray increased. The application of phosphorus, sulphur, and zinc led to a significant increase in protein content in lentil seeds, as shown in Table 1. The highest percentage of protein in the seeds (18.87 and 18.71%) was observed at 50 kg P₂O₅/ha and 25 kg S/ha, respectively. The protein in lentil seed increased from 16.90 to 17.78% with 0.5% ZnSO₄. The presence of Zn in the experiment led to an elevation in protein

content, which can be explained by its involvement in N metabolism. This increase can be primarily attributed to the higher seed yield and protein content observed in lentil. Similar results were also reported by Choudhary *et al.*, (2023).

Nutrient content

The N, P, K, S, and Zn content in lentil seed and haulm were significantly affected by varying levels of phosphorus, sulphur, and zinc during both the years. Table 2 shows that the significantly highest nitrogen, phosphorus, potassium, sulphur, and zinc content in the seed was recorded with 50 kg P₂O₅/ha following by 40 kg P₂O₅/ha. Compared to the application of 30 kg P₂O₅/ha, the use of 40 kg P₂O₅/ha resulted in an increase of 18.51, 18.85, 11.79, 35.29 and 9.79% in nitrogen, phosphorus, potassium, sulphur, and zinc content, respectively. The nitrogen, phosphorus, potassium, sulphur, and zinc content in haulm showed increases of 12.12, 28.23, 9.46, 38.46, and 7.37% respectively, based on the mean data of 2 years. This could be due to the deeper root growth facilitated by phosphorus, leading to higher P content in the crop. An increase in N, P, K, content may be the result of increased phosphorus availability to plants as a result of increased fertilizer levels. Choudhary *et al.*, (2014) observed similar results in soybean.

The application of 25 kg S/ha proved to be the appropriate dosage to boost nitrogen, phosphorus, potassium, sulphur, and zinc content of lentil seed and haulm. On average, this application rate led to a substantial increase of 20.56, 10.88, 9.41, 29.73 and 9.10% in the nitrogen, phos-

phorus, potassium, sulphur, and zinc content in seed respectively, compared to the application of 15 kg S/ha. Similarly, the haulm exhibited equivalent increases of 9.80, 18.34, 9.44, 42.86, and 9.66% in nitrogen, phosphorus, potassium, sulphur, and zinc content, respectively.

Throughout the duration of the study, it was determined that the foliar spray application of 0.5% ZnSO₄ proved to be more effective than the control. Zn foliar spray exhibited a significant increase in nitrogen, phosphorus, potassium, sulphur, and zinc content by 5.15, 4.55, 3.66, 15.00, and 6.03% respectively. Similarly, the haulm showed an increase of 4.72, 7.32, 2.34, 25.00, and 4.51% in nitrogen, phosphorus, potassium, sulphur, and zinc content respectively, compared to the control.

This enhancement in nutrient content within the seed and stover can be attributed to the positive and synergistic impact on nutrient availability resulting from the different rates of fertilizer application through basal and foliar sprays. Similar findings were also reported by Yadav and Singh, (2021), and Chaudhary *et al.* (2023).

Uptake of nutrients

Application of 40 and 50 kg P₂O₅/ha led to a significant increase in the uptake of nitrogen, phosphorus, potassium, sulphur and zinc by seed and haulm compared to 30 kg P₂O₅/ha during both the years. Maximum uptake of nitrogen by seed was recorded with application of 50 kg P₂O₅/ha which was significantly higher than recorded with application of 40 and 30 kg P₂O₅/ha. The uptake of nitrogen, phosphorus, potassium, sulphur and zinc by lentil seed was 28.82, 28.71, 20.84, 47.17 and 19.71% higher, respectively

with 40 kg P₂O₅/ha viz a viz 30 kg P₂O₅/ha. The increases in nitrogen, phosphorus, potassium, sulphur and zinc uptake by haulm with 40 kg P₂O₅/ha to the tune of 28.15, 45.67, 24.00, 55.43 and 21.47%, respectively as compared to 30 kg P₂O₅/ha (Table 3). The increased nutrient uptake can be attributed to the enhanced availability of nutrients to the plant, resulting in higher biomass production. This, in turn, helps to prevent the loss of chlorophyll and leaf nitrogen, thereby promoting photosynthesis. Moreover, the provision of elevated levels of N, P, and K during the flowering and pod filling stages supports these findings, which are consistent with the research conducted by Kundu *et al.*, 2023.

Result showed that sulphur had a substantial impact on the amount of nitrogen, phosphorus, potassium, sulphur and zinc taken up by lentil crop at harvest (Table 3). In comparison to 15 kg S/ha, application of 25 kg S/ha considerably improved the uptake of nitrogen by lentil seed. On mean data basis application of 25 kg S/ha out performed 15 kg S/ha in increasing the uptake of nitrogen, phosphorus, potassium, sulphur and zinc by lentil seed by amounts of 30.92, 20.52, 18.52, 57.52 and 19.00%, respectively. The corresponding increases in nitrogen, phosphorus, potassium, sulphur and zinc uptake by haulm were 21.44, 30.77, 20.94, 60.29 and 21.33%, respectively. The S uptake by lentil grain and straw varied remarkably with the residual S levels. According to Ali *et al.*, (2013) among the different levels, the S uptake increased progressively with the increase in residual S levels from 15 to 45 kg S/ha. The significant residual effect of sulphur on zinc uptake by grain and straw of succeeding lentil crop was observed up

Table 2. Effect of different levels of phosphorus, sulphur and zinc on nutrient content (%) in seed and haulm of lentil (pooled data of 2 years)

Treatment	N content (%)		P content (%)		K content (%)		S content (%)		Zn content (mg/kg)	
	Seed	Haulm	Seed	Haulm	Seed	Haulm	Seed	Haulm	Seed	Haulm
<i>Phosphorus level (kg/ha)</i>										
30	2.43	0.99	0.435	0.209	0.840	1.036	0.34	0.13	27.06	23.06
40	2.88	1.11	0.517	0.268	0.939	1.134	0.46	0.18	29.71	24.76
50	3.02	1.15	0.599	0.288	0.987	1.204	0.50	0.22	30.89	25.03
SEm±	0.015	0.007	0.002	0.001	0.004	0.005	0.002	0.001	0.149	0.128
CD (P=0.05)	0.042	0.019	0.007	0.004	0.012	0.015	0.005	0.002	0.420	0.361
<i>Sulphur level (kg/ha)</i>										
15	2.48	1.02	0.487	0.229	0.871	1.070	0.37	0.14	27.81	22.99
20	2.85	1.11	0.525	0.265	0.934	1.132	0.45	0.19	29.51	24.65
25	2.99	1.12	0.540	0.271	0.953	1.171	0.48	0.20	30.34	25.21
Sem±	0.015	0.007	0.002	0.001	0.004	0.005	0.002	0.001	0.149	0.128
CD (P=0.05)	0.042	0.019	0.007	0.004	0.012	0.015	0.005	0.002	0.420	0.361
<i>Zinc level</i>										
Control	2.70	1.06	0.506	0.246	0.901	1.112	0.40	0.16	28.36	23.75
0.5% ZnSO ₄	2.84	1.11	0.529	0.264	0.934	1.138	0.46	0.20	30.07	24.82
SEm±	0.012	0.005	0.002	0.001	0.003	0.004	0.001	0.001	0.122	0.104
CD (P=0.05)	0.034	0.015	0.006	0.003	0.010	0.012	0.004	0.002	0.343	0.295

Table 3. Effect of different levels of phosphorus, sulphur and zinc on uptake of nutrients (kg/ha) by lentil (pooled data of 2 years)

Treatment	N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)		S uptake (kg/ha)		Zn uptake (g/ha)	
	Seed	Haulm	Seed	Haulm	Seed	Haulm	Seed	Haulm	Seed	Haulm
<i>Phosphorus level (kg/ha)</i>										
30	39.30	33.22	7.07	7.05	13.53	34.88	2.12	4.42	43.59	77.70
40	50.63	42.57	9.10	10.27	16.35	43.25	3.12	6.87	52.18	94.38
50	54.14	44.22	10.73	11.04	17.69	46.12	3.95	8.46	55.37	96.03
SEm±	0.60	0.52	0.11	0.11	0.193	0.505	0.04	0.086	0.576	1.135
CD (P=0.05)	1.69	1.47	0.32	0.32	0.546	1.426	0.11	0.244	1.624	3.203
<i>Sulphur level (kg/ha)</i>										
15	40.98	35.26	8.04	7.93	14.36	36.86	2.26	4.76	45.68	79.09
20	49.44	41.94	9.17	10.06	16.19	42.81	3.37	7.37	51.09	93.05
25	53.65	42.82	9.69	10.37	17.02	44.58	3.56	7.63	54.36	95.96
SEm±	0.60	0.52	0.11	0.11	0.193	0.505	0.04	0.086	0.576	1.135
CD (P=0.05)	1.69	1.47	0.32	0.32	0.546	1.426	0.11	0.244	1.624	3.203
<i>Zinc level</i>										
Control	45.77	37.61	8.54	8.78	15.24	39.48	2.65	5.65	47.74	84.35
0.5 % ZnSO ₄	50.28	42.40	9.39	10.12	16.48	43.35	3.47	7.52	53.02	94.39
SEm±	0.49	0.43	0.09	0.09	0.158	0.413	0.03	0.071	0.470	0.927
CD (P=0.05)	1.38	1.20	0.26	0.26	0.446	1.164	0.09	0.199	1.326	2.615

to 45 kg S/ha. At all the levels of S, most of the P and K were utilized by grain and straw, respectively. This could be due to the balanced nutritional environment inside the plant and higher photosynthetic efficiency which may favour better growth and crop yield and ultimately higher uptake of these nutrients. Similar results were reported by Upadhyay (2013) in lentil.

Data explicit that nutrient uptake by lentil crop was influenced significantly due to zinc application (Table 3). Application of 0.5% ZnSO₄ as foliar spray recorded significantly highest accumulation of nitrogen, phosphorus, potassium, sulphur and zinc during both the years compared to control. On mean data basis, an increase in nitrogen, phosphorus, potassium, sulphur and zinc uptake by seed due to Zn application was to the extent of 9.85, 9.95, 8.14, 30.94 and 11.06%, respectively compared to control. The corresponding increases in nitrogen, phosphorus, potassium, sulphur and zinc uptake by haulm were 12.74, 15.26, 9.80, 33.10 and 11.90%, respectively. The presence of Zn has a favorable effect on photosynthesis and metabolic activities, which in turn boosts the production of photosynthates and their distribution to various plants, such as grain. This ultimately led to an enhanced absorption of N, P, K, S, and Zn by grain and straw, as highlighted by Choudhary *et al.*, (2014) and Kundu *et al.*, (2023).

Hence, it can be concluded that the application of P, S, and Zn significantly affected the yield, nutrient content, and uptake by lentil plants. An effective approach to boost crop productivity in North-Western India could involve ap-

plying 40 kg P₂O₅/ha + 25 kg S/ha + 0.5% ZnSO₄ as a foliar spray on lentil crops.

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