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Fosfor ve Molibden Uygulamalarının Fasulye (*Phaseolus vulgaris*) Saman ve Tanesinin Makro ve Mikro Besin Element İçeriklerine Etkisi

Murat ERMAN[1], Fatih ÇIĞ[2], Ferit SÖNMEZ[3], Mustafa CERITOGLU[2*]

Öne Çıkanlar:

- P ve Mo saman ve tanede N birikimini artırdı
- Mo uygulaması Ca ve Mg alımını teşvik etti
- Birlikte P ve Mo sinerjistik etki gösterdi

Anahtar Kelimeler:

- Biyofortifikasyon
- Kuru fasulye
- Yemeklik baklagil
- Besin alımı
- Bakliyat

ÖZET:

Bu çalışmanın amacı, fosfor (P) ve molibden (Mo) uygulamasının fasulyede makro ve mikro besin biyofortifikasyonuna etkisini incelemektir. Çalışma *Phaseolus vulgaris*'te fosfor ve molibdenin makro ve mikro besin alımı ve biyofortifikasyonu üzerine bireysel ve interaktif etkisine ışık tutmaktadır. Üç fosfor ve molibden seviyesi kullanılan çalışma tesadüf blokları deneme desenine göre dört tekerrürlü olarak yürütülmüştür. Fosfor ve molibden uygulaması hem sap hem de tohumda azot birikimini artırmıştır. Artan fosfor dozlarına bağlı olarak samanda ve tanede azot içeriği kontrole göre sırasıyla %42.3 ve %7.4 oranında artmıştır. Ayrıca, fosfor ilavesi sapta mangan içeriğini artırırken, molibden sapta manganı artırmıştır. Ek olarak, 4 g Mo kg-tohum^{-1} uygulaması tohumdaki magnezyum konsantrasyonunu kontrole göre %28.2 oranında artırmış, ancak deneme alanının toprak bileşiminde bu besinlerin yeterli seviyelerde bulunması nedeniyle bitki materyallerinde fosfor, potasyum, bakır, demir ve çinko içeriğinde bir artış gözlenmemiştir. Çalışma sonuçlarına göre, samanda ve tanede sırasıyla azot %3.15-7.05 ve %17.5-19.2, fosfor 586-990 ppm ve 1049-1355 ppm, potasyum 695-2690 ppm ve 1021-1727 ppm, kalsiyum 5839-11162 ppm ve 559-1303 ppm, magnezyum 690-1474 ppm ve 348-1036 ppm, manganez 25.3-38.3 ppm ve 8.29-9.29 ppm, bakır 8.6-16.9 ppm ve 11.3-19.9 ppm, demir 469-927 ppm ve 70.2-80.3 ppm, çinko 6.5-10.8 ppm ve 17.9-23.3 ppm aralığında değişmiştir. Sonuç olarak, fasulye yetiştirilen alanlarda, özellikle asidik topraklarda, fosfor gübrelemesiyle beraber molibden takviyesinin de gerekli olduğu belirlenmiştir.

Effect of Phosphorus and Molybdenum Applications on Macro and Micro Nutrient Content of Bean (*Phaseolus vulgaris*) Straw and Grain

Highlights:

- P and Mo increased N accumulation in straw and seed
- Mo treatment promoted Ca and Mg uptake
- Combined P and Mo exhibited synergistic impact

Keywords:

- Biofortification
- Dry bean
- Grain legumes
- Nutrient uptake
- Pulse

ABSTRACT:

The aim of this research is to investigate the effect of phosphorus and molybdenum treatment on macro and micronutrient biofortification in bean. The study sheds light on the individual and interactive effects of phosphorus and molybdenum on macro and micronutrient uptake and biofortification in *Phaseolus vulgaris*. Three levels of phosphorus and molybdenum were used in the experiment laid out in a randomized block design with four replications. Phosphorus and molybdenum treatment promoted nitrogen accumulation in both straw and seed. Nitrogen content increased with rising phosphorus doses in straw and seed over control by 42.3% and 7.4%, respectively. Moreover, phosphorus addition increased straw manganese content while molybdenum enhanced straw manganese. In addition, 4 g Mo kg-1/seed treatment boosted seed magnesium concentration over control by 28.2%, however, no phosphorus, potassium, copper, iron, and zinc in the plant materials, likely due to the sufficient levels of these nutrients in the soil composition of the experimental area. According to results, nitrogen, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, zinc varied in straw and seed between 3.15-7.05% and 17.5-19.2%, 586-990 ppm and 1049-1355 ppm, 695-2690 ppm and 1021-1727 ppm, 5839-11162 ppm and 559-1303 ppm, 690-1474 ppm and 348-1036 ppm, 25.3-38.3 ppm and 8.29-9.29 ppm, 8.6-16.9 ppm and 11.3-19.9 ppm, 469-927 ppm and 70.2-80.3 ppm, 6.5-10.8 ppm and 17.9-23.3 ppm, respectively. Consequently, it has been determined that molybdenum supplementation is necessary along with phosphorus fertilization in areas where beans are grown, especially in acidic soils.

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INTRODUCTION

Providing the essential nutrients at optimum levels has a pivotal role in crop yield and quality in plant production. Although nitrogen (N) is the most important nutrient in plant production, legumes can meet their N requirements throughout the vegetation period via symbiotic nitrogen fixation in which effective *Rhizobium* spp. enable atmospheric nitrogen (N_2) to be converted into ammonia for the plant through nodules formed on the roots (Erman et al., 2012; Ahmad et al., 2022). Lentils meet approximately 75% of their nitrogen requirement through this process. Phosphorus (P), the second most important macronutrient after nitrogen, plays a significant role in root and shoot development, flower and seed formation, adenosine triphosphate (ATP) production, nitrogen fixation, developing tolerance to stress factors, as well as influencing yield and quality (Lambers, 2022). Therefore, phosphorus deficiency lies at the core of growth, yield, and quality issues in lentil agriculture. Phosphorus is one of the key nutrient elements due to its involvement in various metabolic processes and its role as a structural component. Phosphorus is vital for plants as it participates in the structure of nucleic acids, phospholipids, carrier molecules such as NAD and NADP, ATP, and other energy-carrying molecules by participating in their formation or structure. Apart from these, it has a pivotal role in some critical processes including photosynthesis, energy transfer, conversion of sugars and starch, transportation of nutrients in plants, and transfer of genes to the next generation. However, its most fundamental role is to facilitate energy transfer to other molecules through phosphorylation (Dissanayaka et al., 2021; Mitran et al., 2018). In addition, essential micronutrients such as molybdenum (Mo) can influence critical processes in plants.

Molybdenum (Mo) is a vital micronutrient for organisms except for specific thermophilic anaerobes which grow optimally at higher than 50 °C and need tungsten instead of Mo (Huang et al., 2022). Molybdenum plays basic role in enzyme systems. More than 50 enzymes containing Mo are recognized, with the majority originating from bacteria, while only a few Mo-enzymes are found among eukaryotes (Sale et al., 2018). Plants experiencing molybdenum deficiency exhibit limited growth and development. Their leaves appear pale, flower formation is disrupted, and the plant wilts. These symptoms arise from insufficient differentiation of vascular bundles during the initial phases of leaf development and localized tissue necrosis. Molybdenum-deficient plants display characteristic phenotypes characterized by altered leaf morphology and lesions (Kaiser et al., 2005). Molybdenum is also substantial for legumes due to regulation and activations of molybdoenzymes such as nitrate reductase, and nitrogenase which is a staple part of root nodulation, i.e., symbiotic N_2 fixation, in legumes (Tiwari, 2018). Another critical role of Mo is the absorption and translocation of iron (Fe) in plants (Verma et al., 2019) since unavailable Fe compounds are converted to available forms via ascorbic acid that is synthesized with active Mo participations (Khan et al., 2014). In addition, it has been documented that Mo addition to plants alters photosynthetic activity, maturation of flowers, Mo status in carbohydrate metabolism, concentration of organic and inorganic P and nutrient availability in plants (Banerjee et al., 2019; Nasar & Shah, 2017; Rahman et al., 2008).

Many researchers studied and reported the effect of individual or interactive impacts of Mo and P in various crops including *Brassica napus* (Liu et al., 2010), *Triticum aestivum* (Nie et al., 2015), *Vigna unguiculata* (Arun et al., 2017), *Lathyrus sativus* (Banerjee et al., 2019), *Lens culinaris* (Tiwari, 2018), *Glycine max* (Sale et al., 2018), *Cicer arietinum* (Chandra et al., 2020), and *Phaseolus vulgaris* (Biswas et al., 2020; Kandil et al., 2013). The experiments indicated above focused on the effects of Mo/P on plant development, agronomic characteristics, biological N_2 fixation (BNF), photosynthesis, cold resistance in plants, or alteration of soil composition. The originality of this research is to insight interactive effect of P and Mo on macro and micronutrient uptake of common bean (*Phaseolus vulgaris*) and their biofortification on straw and seed materials.

MATERIALS AND METHODS

Experimental Material

The Şehirali-90 bean cultivar, which was obtained from Transitional Zone Agricultural Research Institute, was used in the field experiment. The cultivar is dwarf, upright-growing, medium-early maturing, tolerant to viral and bacterial diseases, with a rooster-shaped seed and white seed color. Triple superphosphate (42%) and sodium molybdate ($Na_2MoO_4.2H_2O$) were used for P and Mo application, respectively. The Rhizobium strain was obtained from the Ankara Soil and Fertilizer Research Institute.

Climatological Characteristics of The Experimental Area

Area belonging to the Faculty of Agriculture at Van Yüzüncü Yıl University was used as experimental site. The geographical coordinates of the trial area are between 38° 54' - 39° 25' North latitude and 42° 04' - 44° 23' East longitude. The elevation of the location above sea level is 1725 meters.

The region experiences a continental climate. Due to the high altitude, winters are characterized by heavy snowfall and harsh conditions. Throughout the trial season, the total precipitation (167.5 mm) was found to be higher compared to the long-term yearly average (LYA) precipitation (145.1 mm). In terms of average temperatures, the lowest (8.4 °C) and highest (23.1 °C) temperature values were recorded in April and July, respectively. During the trial period, monthly average relative humidity values ranged from 53.4% to 73.0%. Monthly average precipitation, temperature, and relative humidity values for the trial period and the long-term yearly average (LYA) are presented in Figure 1.

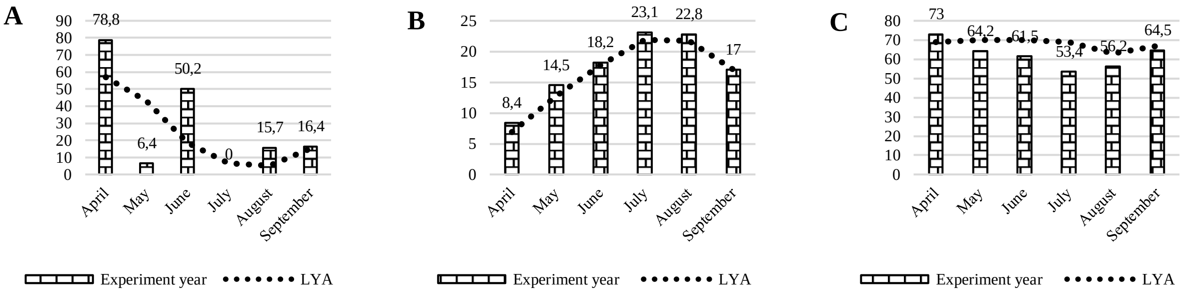

Figure 1. Climatological data for Van Province (A: Precipitation (mm), B: Temperature (°C), C: Relative humidity (%), LYA: Long years average covers the years from 1938 to 2003)

Soil Physio-Chemical Characterization of Experimental Site

Electrical conductivity (EC) and soil reaction (pH) were determined using the 1:2.5 soil-water mixture method. Lime was detected using the calcimeter method. The Bouyoucus hydrometer method was used for texture analysis. Walkley Black wet combustion method was subjected to determine organic matter content (De Vos et al., 2007). Phosphorus was calculated by sodium bicarbonate method using a spectrophotometer (Schoenau & O'halloran, 2008), and potassium concentration of experimental site was determined using the flame photometer method (Ferrando et al., 2020). Results indicated that the soil is characterized by clay loam (CL) and slightly acidic pH in both 0-20 and 20-40 cm. Similarly, experimental soils are mid-lime, with no salty and low organic matter in both depths. Available nitrogen is enough and low in the 0-20 and 20-40 cm, respectively. Olsen-P is sufficient in both depths. Available K was high in both 0-20 and 20-40 cm (Table 1).

Table 1. Chemical composition and characteristics of experimental soil in depths of 0-20 and 20-40 cm

Depth (cm)	Sand-Silt-Clay (%)	Texture	pH	Lime (%)	EC (%)	OM (%)	N (%)	P (ppm)	K (ppm)
0-20	27.8-3.4-38.2	Clay-loam	6.5	17.9	0.021	1.85	0.092	6.71	560
20-40	29.8-3.0-40.2	Clay-loam	6.4	13.2	0.019	1.81	0.086	4.22	221

(OM: Organic matter, EC: Electrical conductivity)

Experimental Plan and Laying out

The study was conducted in 2003 using a completely randomized design (CRD) with four replications. In the trial, 3 levels of phosphorus (P0: Control, P1: 20 kg P2O5 1/ha, P2: 40 kg P2O5 1/ha) and 3 doses of molybdenum (Mo0: Control, Mo1: 2 g Mo kg-1/seed, Mo2: 4 g Mo kg-1/seed) were used. All plots received 25 kg N 1/ha of pure nitrogen in the form of ammonium sulfate. Nitrogen and phosphorus fertilizers were applied beneath the seedbed at sowing. Molybdenum was weighed according to the treatments, adequately diluted, and then applied to the seeds. The seeds were inoculated with *Rhizobium phaseoli* strain immediately before sowing. During inoculation, 1 kg of pit culture was used for 50 kg of seeds, and 1.5% gum arabic was used to adhere it to the seed surface (Lupi et al., 1988). Sowing was done manually in the second half of May.

In the trial, there was a distance of 2 m between the blocks and 1 m between the plots. Plots measuring 4 m x 2.5 m = 10 m^2 were used, with planting rows spaced 50 cm apart and seeds sown at intervals of 5 cm within rows. The trial was conducted under irrigated conditions, and irrigation was carried out nine times, taking into account rainfall, air temperature, and soil moisture. Irrigation was performed using a drip irrigation system. Manual weeding was carried out when necessary during the trial period to control weeds. No pesticides were used during the experiment as no symptoms of disease or pests were observed. Plants were harvested in September, 2003.

Macro and Micronutrient Composition of Straw and Seed Materials

Straw and seed materials were collected and labelled. The materials were ground into powder and made ready for physical analysis. A 0.5 g of material was weighed into porcelain crucibles and burned in a muffle furnace at 500 °C. The burnt material was filtered into volumetric flasks and made up to the line with distilled water (Erman et al., 2024). Phosphorus, calcium, magnesium, iron, manganese, zinc and cupper were determined by the ICP-OES spectrophotometry method (Hansen et al., 2013). Total nitrogen was calculated by method of Dumas (Wang & Daun, 2006). Potassium content in the plant was determined using a flame photometer (Ferrando et al., 2020).

Statistical Analysis

Analysis of variance was subjected to data based on the CRD. Tukey's Honestly Significant Difference (HSD) test was used for the grouping of means for dependent variables using “agricolae” package R software.

RESULTS AND DISCUSSION

Results

The results indicated that P, Mo and PxMo interaction caused statistically significant differences ($p<0.05$ or $p<0.01$) in macro and micronutrient concentration of straw or seed. Phosphorus addition to experimental soil significantly affected straw N and Mg at the level of %1 and Zn at the level of %5, while it caused a statistically significant difference ($p<0.01$) in seed N, Ca and Mg. The Mo treatment led to significant differences ($p<0.01$) in N and Ca in both straw and seed. In addition, Mo treatment significantly changed the Mn concentration of straw and Mg content of seed material at the level of 5% and 1%, respectively. PxMo interaction caused statistically significant differences at the level of 1% and

5% in straw and seed P concentrations, respectively. The PxMo interaction significantly ($p<0.01$) affected seed N content while it causes significant differences in K, Ca and Mg content in straw (Table 2).

Table 2. Analysis of variance for phosphorus and molybdenum treatments on micro and macronutrient availability in straw and seed of experimental material

	Sum of square/F prob.					
Nutrient	Phosphorus		Molybdenum		PxMo	
	Straw	Seed	Straw	Seed	Straw	Seed
Nitrogen	21.31**	11.16**	24.10**	2.02**	0.94ns	1.28**
Phosphorus	71206ns	38654ns	6718ns	50198ns	238942**	157488*
Potassium	1246038ns	46333ns	1899247ns	373350ns	8088413**	729941ns
Calcium	817673ns	710356**	48725531**	857697**	33396734**	258395ns
Copper	46.3ns	10.15ns	65.5ns	45.87ns	163.80ns	152.59ns
Iron	217233ns	119.9ns	115743ns	5.3ns	176960ns	381.2ns
Magnesium	219142ns	934266**	223674ns	477516**	1904258**	137571ns
Manganese	266.6**	0.670ns	180.6*	0.680ns	69.8ns	1.115ns
Zinc	38.9*	27.3ns	6.2ns	29.9ns	13.5ns	44.1ns

(*: $p<0.05$, **: $p<0.01$, ns: no significant difference)

Effects of phosphorus application on micro and macro nutrient concentration

The highest N content in straw (6.33%) and seed (3.02%) was determined with P2 treatment, whereas the lowest N concentration in straw (4.45%) and seed (2.82%) was observed in control plants. Phosphorus concentration changed between 768-829 ppm and 1183-1264 ppm in straw and seed materials, respectively. Potassium content of straw and seed varied between 1666-2084 ppm and 1388-1476 ppm, respectively. Phosphorus was effective on Ca and Mg accumulation in seed, but no straw. Accordingly, the highest (1034 ppm) and lowest (690 ppm) Ca content was determined in control and P2-treated plants, while the maximum (882 ppm) and minimum (515 ppm) Mg was observed in control and P1-treated plants, respectively. Phosphorus was effective on Mn accumulation in straw, but no seed. The lowest (27.0 ppm) and highest (33.6 ppm) Mn content was determined in P1- and P2-treated plants, respectively. Differences among Cu and Fe concentrations were not statistically significant both in straw and seed. The highest straw Zn content was determined as 10.7 ppm in control plants, whereas the lowest one was observed as 8.2 ppm in P1-treated plants (Figure 2).

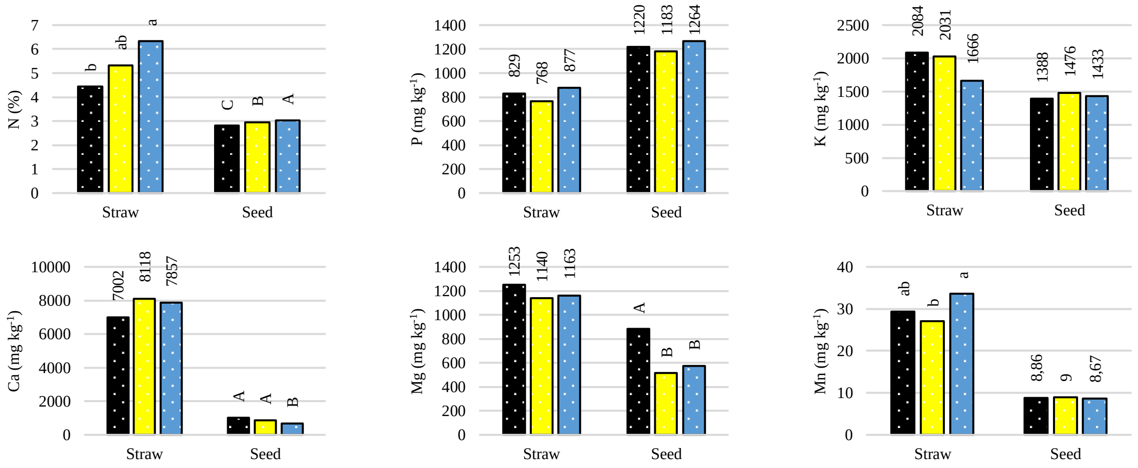

Figure 2 Alteration of macro and micronutrient concentrations of bean straw and seed under different phosphorus conditions (P0: Control, P1: 20 kg P_2O_5 1/ha, P2: 40 kg P_2O_5 1/ha)

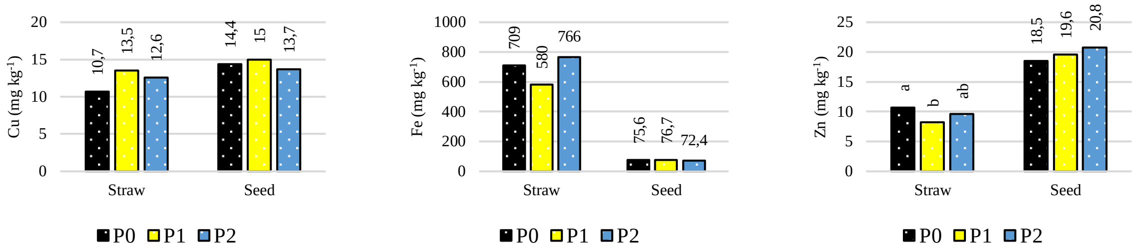

Figure 2 Alteration of macro and micronutrient concentrations of bean straw and seed under different phosphorus conditions (P0: Control, P1: 20 kg P_2O_5 1/ha, P2: 40 kg P_2O_5 1/ha)

Effects of molybdenum treatment on micro and macro nutrient concentration

Molybdenum treatment promoted N uptake and accumulation in both upper leaves and seeds. The highest N content in straw (6.0%) and seed (18.5%) were determined with P1 and P2 treatments, respectively, whereas the lowest ones were observed in straw (4.2%) and seed (18.0%) in control plants. Molybdenum treatment negatively affected straw Ca concentration while seed Ca concentration irregularly changed with Mo treatment. The calcium concentration of straw changed between 6721-9298 ppm. In seed, P1 treatment reduced Ca accumulation by 649 ppm, however, P2 increased it up to 975 ppm. Although Mo treatment did not significantly affect straw Mg content, it changed between 1097-1264 ppm and increasing Mo doses reduced Mg content in straw. In contrast, Mo treatment was effective on seed Mg and also increased Mg accumulation from 631 ppm to 809 ppm over control. Increasing Mo level promoted Mn concentration in straw, in which the lowest and highest Mn levels were 27.5 and 32.9 ppm, respectively. On the other hand, Mo treatment was not significantly effective on P, K, Cu, F and Zn accumulation in both straw and seed (Figure 3).

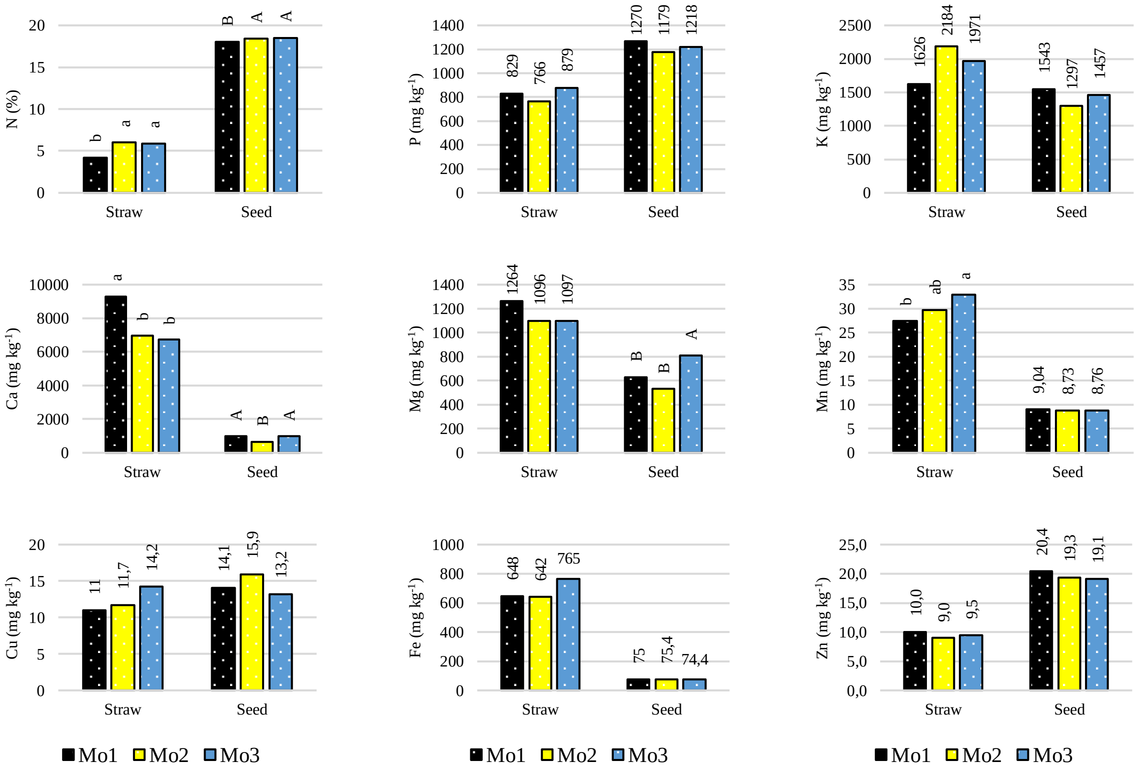

Figure 3 Alteration of macro and micronutrient concentrations of bean straw and seed under different molybdenum treatments (Mo0: Control, Mo1: 2 g Mo kg-1/seed, Mo2: 4 g Mo kg-1/seed)

Effects of P x Mo interaction on micro and macro nutrient concentration

PxMo interaction noteworthy altered P, K, Ca and Mg in straw as well as N and P in seed tissues. The highest seed N content (19.2%) was determined in Mo1 and Mo2 treatment under P2 conditions, whereas the lowest one (17.5%) was observed in P0-Mo0 (control) plants. The highest straw K (2690 ppm) was determined in Mo1 and P1-treated plants, while the lowest straw K was observed in P1-treated but no Mo conditions. Straw and seed P accumulation exhibited a similar reaction, i.e., increasing P and Mo promoted P content in straw and seed. The lowest (5954 ppm) and highest (11161 ppm) straw Ca were determined in Mo2 with no phosphorus and P1 with no Mo, respectively. Straw Mg changed between 690-1474 ppm, in which P and Mo treatment almost negatively affected it (Table 3).

Table 3. Effect of PxMo interaction on macronutrient concentration of straw/seed material of bean

Trait	P	Mo0	Mo1	Mo2	Trait	Mo0	Mo1	Mo2
Seed N (%)	P0	17.5 d	17.6 d	17.6 d	Straw K (ppm)	1717 ab	1932 ab	2445 a
	P1	18.3 c	18.5 bc	18.8 ab		695 b	2690 a	1612 ab
	P2	18.2 c	19.2 a	19.2 a		2466 a	1929 ab	1856 ab
Straw P (ppm)	P0	834 ab	893 a	762 ab	Seed P (ppm)	1224 b	1231 ab	1205 ab
	P1	884 ab	586 b	886 a		1355 a	1049 b	1146 ab
	P2	821 ab	821 ab	990 a		1231 ab	1257 ab	1303 a
Straw Ca (ppm)	P0	7315 bc	7735 bc	5954 c	Straw Mg (ppm)	1415 a	1474 a	870 bc
	P1	11161 a	5839 c	7353 bc		1369 ab	690 c	1362 ab
	P2	9418 ab	7297 bc	6855 bc		1008 a-c	1123 a-c	1058 a-c

(P0: Control, P1: 20 kg P_2O_5 1/ha, P2: 40 kg P_2O_5 1/ha, Mo0: Control, Mo1: 2 g Mo kg-1/seed, Mo2: 4 g Mo kg-1/seed)

Discussion

Increasing N accumulation in straw and seed was recorded with P and Mo applications in the experiment. In contrast to other nutrient elements, N accumulation in plants varies depending on BNF, since legumes can convert N_2 into ammonia in the nodules located in the root zone under the presence of appropriate rhizobium strain in the soil (Baber et al., 2023). Therefore, environmental factors affecting BNF can directly influence the amount of N acquisition by plants. Moreover, BNF requires high energy and involves a complex mechanism. Since P is one of the key elements in cellular energy mechanisms, the application of P has a positive effect on BNF (Singh & Singh, 2016). Jindal et al. (Jindal et al., 2008) found that increasing P doses up to a certain level increased nodule formation and nodule dry weight, but higher than 80 kg P_2O_5 1/ha reduced the number of nodules. Also, the availability of P in the rhizosphere promoted root development, thereby, increasing nodulation (Singh et al., 2005). On the other hand, it is well known that Mo is a key element for BNF due to its role in controlling nitrate reductase and nitrogenase (Khan et al., 2014; Li et al., 2023). Singh et al. (Singh et al., 2017) examined the effects of P and Mo applications on nutrient element contents in lentils and reported an increase in N content in the plant compartment with increasing P doses. Moreover, in the assimilation pathway nitrate reductase is the key primary enzyme which is why in plants deficiency of Mo often leads to N deficiency (Nowak et al., 2004). On the other hand, Pedas et al. (Pedas et al., 2011) reported that higher P supplementation promoted N accumulation in barley leaves.

Phosphorus treatment did not affect P and K accumulation in straw and seed due to enough and high availability of them in experimental soil, respectively. In addition, Mo treatment also did not affect the P and K acquisition of plants. It can be explained that plants already can meet the required P and K from stand establishment to harvest, therefore, more treatment of them did not change taking up these nutrients. On the other hand, P and Mo treatment enhanced Mn accumulation in both straw and seed. Shi et al. (Shi et al., 2021) indicated that high phosphorus addition increases Mn concentrations with high bioavailability in wheat grains and it alters the speciation and distribution of Mn. Siskavardani et al. (Devi Dwi Siskawardani, 2015) claimed that higher Mn accumulation with P fertilizer could be caused due to vitality, growth and transpiration rate in plants. Siskavardani et al. indicated that the possibility mechanism starts with Mn transport as a cation and coordinates with O_2 donors in plants that will be higher at the high P concentration. Researchers reported that higher P concentration promotes Mn accumulation in barley (Zhu et al., 2002), sorghum (Galvez et al., 1989), wheat (Pearson & Rengel, 1994) and Arabidopsis (Himelblau & Amasino, 2001). In addition, Mo2 addition promoted Mn accumulation in straw, but no seed. Basak et al. (1982) reported that Mo treatment increased Mn uptake and accumulation in shoots and roots in rice. Molybdoenzymes can be categorized based on their involvement in N assimilation and reduction in plants. These enzymes include nitrogenase, nitrate reductase, indole-3 acetic acid synthesis, sulfur metabolism, abscisic acid synthesis, and purine metabolism. Both sulfur metabolism and nitrate reductase utilize a dioxo Mo-cofactor, which activates proteins when incorporated into a protein complex. (Mendel & HaÈnsch, 2002). Therefore, it is thought that Mo treatment has many direct and indirect effects on nutrient uptake, accumulation and transportation in plants. So, Mo treatment also increased Ca and Mg accumulation in straw. Nutrient uptake in plants is related to many complex relationships based on antagonism or synergism among nutrients (Ceritoglu, 2024). Thus, P treatment reduced the concentration of Zn in straw and Ca and Mg in seed via the relationship of nutrient uptake mechanisms (Ceritoglu, 2024; Printz et al., 2016; Xie et al., 2021).

In the general perspective of interaction, PxMo promoted N, P and Mg accumulation whereas it inhibited K uptake in plants. Researchers reported that high P availability in soils K uptake by plants i.e., exhibiting antagonistic effect (Ródenas et al., 2019). the systems and mechanisms regarding how plants detect nutrients in the rhizosphere and accordingly determine how much other nutrient elements need to be taken up have not been fully elucidated yet (Wang et al., 2020) Additionally, parallel to increasing P doses, the amount of Ca taken up by plants has increased. Ca^{+2}, Mg^{+2}, and K^{+} ions are quite similar in size and charge, and therefore, the cation exchange sites on roots cannot distinguish between ions (Malvi, 2011). Therefore, higher Ca uptake due to P fertilization in soils limits K uptake. Ca^{+2}, Mg^{+2} and K^{+} ions are quite similar in size and charge, and therefore, cation exchange sites on the roots cannot distinguish the difference between the ions (Malvi, 2011). Often, these regions receive both ions indiscriminately, regardless of which ion it is. Therefore, increased Mg uptake due to competition between cations may have led to the limitation of K uptake.

CONCLUSION

Biofortification of agricultural products, especially in developing countries where dietary habits rely heavily on agricultural produce, holds a critical position in both human and animal nutrition. This study focused on the effects of phosphorus and molybdenum applications on the macro and micronutrient contents of both the straw and seed materials of beans. The research found that phosphorus and molybdenum applications significantly increased the total nitrogen content in both the seed and straw. Additionally, it was determined that these applications promoted the accumulation of manganese, magnesium and calcium in plants. However, they did not have a significant effect on the accumulation of phosphorus, potassium, copper, iron, and zinc in the plant materials, likely due to the sufficient levels of these nutrients in the soil composition of the experimental area. Consequently, it was concluded that in areas where beans are cultivated, molybdenum application should not be neglected, especially in acidic soils, in addition to phosphorus fertilization.

Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

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