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Selected Drybean Yield Parameters Affected by Phosphorus Fertilizer Sources under Different Locations of North-West Province, South Africa

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ABSTRACT

Drybean (*Phaseolus vulgaris* L.) is a significant source of protein and other essential macro- and micronutrients for human nutrition. This study was carried out in three ecologically different locations in the 2019/2020 growing season to assess the effect of phosphorus fertilizer source and environmental variations on selected drybean grain yield and quality. The experiment was a 3×4×2 factorial experiments fitted into a Randomized Complete Block Design (RCBD), with four replications. The three experimental sites were Mafikeng, Kraaipan and Taung. The four phosphorus fertilizer sources were the control, single superphosphate (SSP), mono-ammonium phosphate (MAP) and maxi phos. The two drybean cultivars used in this study were PAN 9292 and PAN 148. Yield and quality parameters measured were, number of pods per plant, number of seed per pod, pod length, pod mass, ash, and fat content. Phosphorus fertilizer source had a significant effect on the ash content. The ash content of drybean treated with SSP was significantly higher. The pods number of each plant, length of pods, and pod mass were all significantly affected by location. Drybean planted in Mafikeng produced significantly higher pods number of each plant, longer pods, and higher pod mass than at the other locations. The ash and fat content were significantly affected by the location. The ash and fat content of drybean grown in Mafikeng were 2.23% and 2.93%, respectively. Drybean treated with monoammonium phosphate (MAP) showed higher number of pods per plant and longer pods length.

Keywords: drybean, phosphorus fertilizer source, location, yield, quality.

INTRODUCTION

Drybean (*Phaseolus vulgaris* L.) is a popular staple food crop in many South African households and an important protein supplement and in addition to promoting sustainable agricultural production systems, play a significant role in the global food supply chain (Siddiq et al., 2022). Less than 1% of all summer field crop production in South Africa is made up of the relatively small amount of dry beans, which have an average annual production of 65,000 tons over the past five years (Esterhuizen, 2021). Utilization of grain legumes is influenced by a variety of variables, such as crop environment, bean cultivar choice, and bean type. Furthermore, these factors have a significant impact on nutrient content and bioavailability (Siddiq and Uebersax, 2022). Genotype by environment interactions is more common in beans than in most other crops (Olle and Tamm, 2021).

Due to the production of proteins containing compounds, in which N and P are significant constituents, legumes, including common beans, have a high P requirement. Additionally, the P concentration in legumes is typically much higher than that of grasses (Nigatie, 2021). The use of diammonium phosphate increased the number of pods produced per plant significantly. Therefore, the increase in the number of pods per plant caused by the treatment of P fertilizer emphasizes the hypothesis that P fertilizer enhances the development of nodes and pods in legumes (Turuko and Mohammed, 2014).

Modern dry bean cultivars when challenged with water deficit, tend to have ability to retain and fill pods as compared with drought susceptible cultivars (Uebersax et al., 2022). Indeterminate bean cultivars are higher yielding under stress and have a greater positive response to more productive environments compared to determinate cultivars (Nleya et al., 1999). According to

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Koch et al. (2018) one genotype outperformed the other genotypes in terms of the number of seeds produced per pod and the number of pods produced per plant. Barampama and Simard (1993) reported that ash and fat of drybean varieties had respective average values of 4.47 and 1.1 percent.

Other studies have demonstrated that the most significant environmental factors influencing the drybean's growth, development, and biological yield are light and temperature (Abou Hadid, 2012), their impact times and topographic characteristics are crucial for determining the yield and quality of dry bean seeds (Sozen et al., 2018). High temperatures during seed development, especially at night, hasten the ripening of shelled seeds and reduces the nutritional value of seeds (Nemeskéri, 2012). The amount of fat and starch indicated significant environmental effects on dry bean (Rodiño et al., 2009). Therefore, the objective of this study was to evaluate the effect of phosphorus fertilizer sources and environmental variations on selected drybean yield and nutritional quality parameters.

MATERIAL AND METHODS

Study site description

The research was carried out in three environmentally different locations of North-West province of South Africa during 2019/2020 planting season. The first site was at Mafikeng in the North-West University experimental farm, situated at 25°48′S and 45°38′E and at an altitude of 1 012 meters above sea level. The University's experimental farm lies in a semi-arid tropical savannah climate geographical area which receives summer precipitation totals 571 mm on average per year (Kasirivu et al., 2011). Summer temperatures in Mafikeng range between 22°C and 34°C. The experimental farm has red soils with a sandy loam texture, and the soils at the site are classified as Hutton series by the South African soil classification (Molope, 1987; Kasirivu et al., 2011).

The second location for this research study was at Kraaipan, in a farmer's field, situated at 26.294° S and 25.297° E, and at an altitude of 1 269 meters above sea level. The temperature in Kraaipan ranges between 17°C and 32°C and the mean annual rainfall is between 200 and 600 mm. The experimental site is in a semi-arid geographical area and the soils are classified as the Hutton series that have a loamy sand soil texture.

The third location was the Department of Agriculture experimental station in Taung, situated at 27° 30'S and 24° 30'E, and at an altitude of 1 111 meters above sea level. The experimental station is in a grassland savannah geographical area and has an average rainfall of 1061 mm beginning in October. The soil at the location belongs to the Hutton series, according to the South African soil classification (Molope, 1987; Kasirivu et al., 2011). Summer temperatures in Taung range between 18°C and 32°C. Taung features eutrophic soils with parent material derived from aeolian deposits that are deep, fine sandy, mostly red, and well-drained (Soil Survey Staff, 1999). Table 1 shows the weather data for the three locations considered in this study.

Table 1. The average temperature and rainfall in Mafikeng, Kraaipan, and Taung during 2019/20 planting season

Location	Climatic data	Oct.	Nov.	Dec.	Jan.	Feb.	Mar	Apr.	May
Mafikeng	Rainfall (mm)	0.6	54.6	160.4	106.4	52.2	88	46.8	0.0
	Max T (ºC)	33.6	33.3	30.2	30.7	31.1	28.4	25.8	24.6
	Min T (ºC)	15.6	17.5	18.1	17.4	17.8	14.8	11.6	5.7
Kraaipan	Rainfall (mm)	0.03	1.2	4.5	2.3	2.3	4.1	2.8	0.0
	Max T (ºC)	33.6	33.1	30.1	30.4	31	28.4	25.8	24.6
	Min T (ºC)	15.3	17.9	17.6	17.5	17.7	14.7	11.0	5.9
Taung	Rainfall (mm)	0	9.4	76.6	57.6	128	106	65.8	0.0
	Max T (ºC)	34.2	36.8	33.4	34.2	31.7	30.3	26.6	25.8
	Min T (ºC)	13.2	16.5	18.5	18.9	18.6	15.6	11.3	4.1

Experimental design and treatments

The experiment was a 3×4×2 factorial experiment fitted into a Randomized Complete Block Design (RCBD) with four replications; each replication had eight treatment combinations. The three experimental sites were at Mafikeng, Kraaipan and Taung. The experiment consisted of four fertilizer sources of phosphorus which included a control, single superphosphate, monoammonium phosphate, and maxi phos. There were two different cultivars used, namely PAN 9292 and PAN 148. The experiment at each location had a total of 32 plots.

Measurement of agronomic traits

Within each plot, drybean yield data was collected from the harvested area of 10.2 m^2. The data collected at the agronomic maturity stage included the number of pods per plant, pod length, number of seeds per pod and pod mass. The number of pods in each plant was counted from the seven marked plants per plot and averaged. Seven pods, collected from the plants in the middle rows of each plot, were measured in centimeters and averaged. The number of seeds per pod was counted by opening each pod from the seven marked plants in each plot and averaged. Pod mass per harvested area was measured by weighing the pods harvested from each plot and recorded. The pods were threshed, cleaned, and samples of 200 g were weighed at the university laboratory. The drybean grain seeds were then weighed and delivered to Döhne Analytical Services in Eastern Cape Province, where they were evaluated for ash and fat content using a Near Infrared Reflectance Grain (NIR) analyzer.

Data analysis

The collected data were subjected to an analysis of variance (ANOVA) of Gen-Stat Discovery Edition 4 to compare the effects of treatment factors on the drybean parameters. The least significant difference (LSD) was used to separate treatment means at a 5% probability level of significance. Under the measured parameters, the high-rate interaction values were considered.

RESULTS AND DISCUSSION

The sources of phosphorus fertilizer and cultivar had no significant effect ($P \geq 0.05$) on the number of pods per drybean plant (Table 2). Even though no significant differences in sources of phosphorus fertilizer were discovered, MAP-treated drybean produced a higher number of pods per plant of 14.54 compared to drybean treated with other phosphorus sources. The higher number of pods per plant observed on drybean treated with MAP might be attributed to the metabolic role that P and N play in enhancing the development of a canopy and pod setting of drybean. This statement is consistent with the results of Kumar et al. (2013), who indicated that mono-ammonium phosphate increased the number of pods each plant of soybean. Munyinda et al. (2019) further discovered that the addition of mono-ammonium phosphate increased common bean number of pods highly significant by about 300%.

The number of pods per drybean plant was significantly affected ($P < 0.05$) by location. Drybean grown in Mafikeng produced a notably higher number of pods of 18.96 as compared to the results for Kraaipan and Taung (8.87 and 12.7). As indicated in Table 1, the higher number of pods produced by each plant observed at Mafikeng might be attributed to the optimum rainfall that was received by this location during the growing period. This observation substantiates the findings of Islam and Sebetha (2020), who stated that adequate rainfall during the drybean's flowering, and growth period resulted in an increase in the number of pods produced by each drybean plant. The interactions of all treatment factors had no significant effect ($P \geq 0.05$) on the pods number per drybean plant.

The sources of phosphorus fertilizer had no significant effect ($P \geq 0.05$) on drybean pod length (Table 2). Even though there was no significant difference between the sources of phosphorus fertilizer, MAP-treated drybean produced longer pods of 11.96 cm compared to drybean treated with other P sources. The longer length of pods observed on drybean treated with MAP might be attributed to the availability of plant nutrients which stimulated the plants to produce longer pods. This is due to MAP being water-soluble and enhanced pod development. This statement is similar to the findings of Munyinda et al. (2019), who discovered that mono-ammonium phosphate increased the length of pods significantly.

Cultivar had significant effect ($P \leq 0.05$) on the length of drybean pods. Cultivar PAN 148 produced significantly longer pods of 12.21 cm than those produced by cultivar PAN 9292 (11.34 cm). PAN 148 cultivar's longer pod length could be attributable to the determinate cultivars' growth habits and the genotype being able to respond to favorable environments. This observation concurs with the results of Mulungu et al. (2006), who indicated that during the wet season, determinate bean cultivars typically produce longer pods; however, during the dry season, indeterminate bean cultivars produce longer pods.

Location had a significant effect ($P \leq 0.05$) on the length of drybean pods. Drybean planted at Mafikeng produced significantly longer pods of 12.74 cm than those produced at Kraaipan and Taung (11.70 and 10.87 cm). The longer pod length observed at Mafikeng might be attributed to the amount of received rainfall during the growing period. This observation agrees with the results of Abebe et al. (2020), who indicated that the effects of the frequency of irrigation and the interaction of the depth and frequency of irrigation on the length of pods are significant. The interaction between location × cultivar had a significant effect ($P \leq 0.05$) on drybean pod length.

As shown in Table 2, phosphorus fertilizer source had no significant effect ($P \geq 0.05$) on drybean number of seeds per pod. Cultivar had significant effect ($P \leq 0.05$) on the number of seeds per drybean pod. PAN 148 cultivar produced a notably higher number of seeds each pod of 5.65 as compared to the number of seeds per pod produced by cultivar PAN 9292 (4.65). The higher number of seeds per pod observed on drybean cultivar PAN 148 might be attributed to the determinate cultivar’s genetic makeup and growth habit characteristics. This observation concurs with the results by Klimek-Kopyra et al. (2015) who reported that the highest number of seeds per pod were produced by the determinate variety.

Location had a significant effect ($P \leq 0.05$) on the number of seeds per pod. Drybean planted at Kraaipan produced a significantly higher seeds number per pod of 5.39 than seeds number in each pod produced at Mafikeng and Taung (5.35 and 4.71). The higher number of seeds each pod observed at Kraaipan might be credited to environmental factors, such as temperature and rainfall. As indicated in Table 1, the temperature and rainfall at Kraaipan were found to be moderate as compared to these climatic elements at Mafikeng and Taung. This observation agrees with similar findings of Sebetha and Modi (2016) who reported that, seed per pod is significantly affected by interaction of location and season. The interaction of location × cultivar had a significant influence (P ≤ 0.05) on the seeds number per pod.

The sources of phosphorus fertilizer and cultivar had no significant effect (P ≥ 0.05) on drybean pod mass (Table 2). Even though no significant differences in sources of phosphorus fertilizer could be found, maxi phos-treated drybean produced a higher pod mass of 2071.08 kg/ha as compared to drybean treated with other phosphorus sources. The higher pod mass observed on drybean treated with maxi phos might be attributed to the high-water solubility level (93%) of the fertilizer and its high P content that together increase the supply of nutrients to the plant, and which consequently lead to an increase in pod weight. This statement agrees with the findings by Youssef et al. (2017), who indicated that the pod weight of snap bean is significantly influenced by phosphorus sources, MAP and calcium superphosphate, which together constitute maxi phos.

Drybean pod mass was significantly affected by location (P ≤ 0.05). Drybean grown in Mafikeng produced notably higher pod mass of 3232.23 kg/ha as compared to that produced at Kraaipan and Taung (1583.95 and 1084.56 kg/ha). As indicated in Table 1, the higher pod mass observed at Mafikeng could be attributed to the amount of rain that Mafikeng received during the physiological maturing stage of the drybean plant. This observation correlates with the findings by Saleh et al. (2018), who indicated that the weight of the pods is generally increased by applications of moderate water volume. Interaction of location × cultivar had a significant impact (P ≤ 0.05) on drybean pod mass.

Table 2. The effect of phosphorus fertilizer source, cultivar, and location on the number of pods per plant, pod length (cm), seeds per pod and pod mass

Treatment factors	Pods per plant	Pod length	Seeds per pod	Pod mass
Phosphorus sources				
MAP	14.54	11.96	5.23	2054.74
MAXI	13.97	11.83	5.25	2071.08
SSP	13.22	11.80	5.00	1830.07
Control	12.31	11.49	5.13	1911.76
$LSD_{(0.05)}$	2.03	0.34	0.32	299.28
Location				
Kraaipan	8.87	11.70	5.39	1583.95
Mafikeng	18.96	12.74	5.35	3232.23
Taung	12.7	10.87	4.71	1084.56
$LSD_{(0.05)}$	1.76	0.30	0.28	259.29
Cultivar				
PAN 148	13.53	12.21	5.65	2044.53
PAN 9292	13.48	11.34	4.65	1889.30
$LSD_{(0.05)}$	1.43	0.24	0.23	211.63
Interactions				
P.S × L	NS	NS	NS	NS
P.S × C	NS	NS	NS	NS
L × C	NS	**	**	**
P.S × L × C	NS	NS	NS	NS

P.S = Phosphorus fertilizer source, L = Location, C = Cultivar, ** = significant, NS = not significant.

As shown in Figure 1, phosphorus fertilizer source and cultivar had no significant effect (P ≥ 0.05) on the ash content of drybean. Even though no significant differences in sources of phosphorus fertilizer could be found, SSP-treated drybean produced a higher ash content of 2.11% compared to drybean treated with other phosphorus fertilizer sources. The higher ash content observed in drybean treated with SSP might be attributed to single superphosphate being highly water soluble and thus able to raise the drybean nutrient content. This observation agrees with the findings by Fouda (2017), who stated that separately, there was a substantial increase in the ash content of the faba bean from the use of single superphosphate.

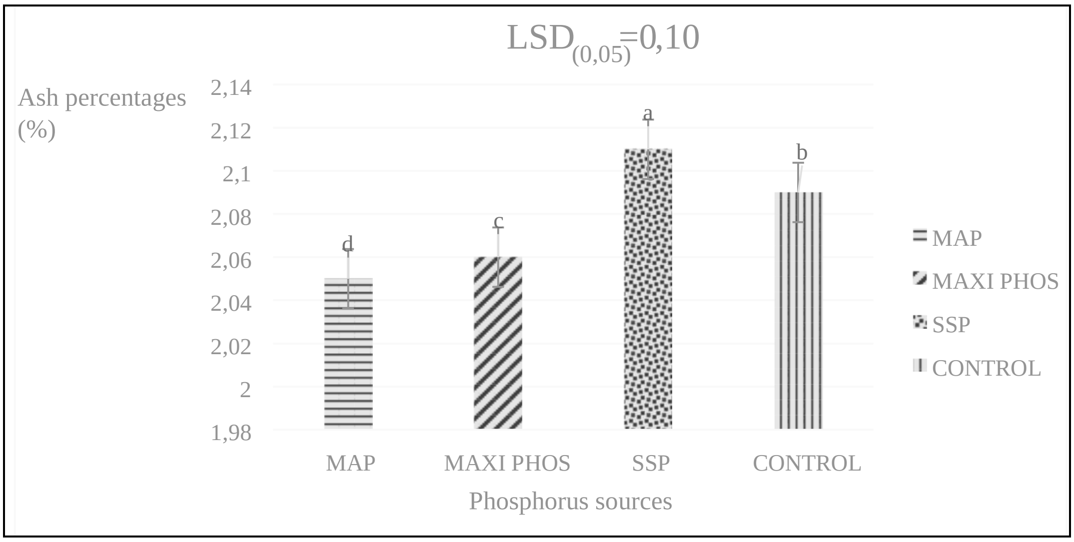

Figure 1. The influence of different phosphorus fertilizer sources on drybean ash content

As shown in Figure 2, location had a significant effect ($P \leq 0.05$) on the ash content of drybean. Drybean planted in Mafikeng had a significantly higher ash content of 2.23% as compared to other locations. The higher ash content observed at Mafikeng might be attributed to the rainfall, the quality of the soil and the availability of soil nutrients. This observation concurs with the findings by Kanda et al. (2020), who observed a higher ash content in cowpea under high irrigation water regimes. The interaction of location × cultivar had a significant effect ($P \leq 0.05$) on the ash content of drybean.

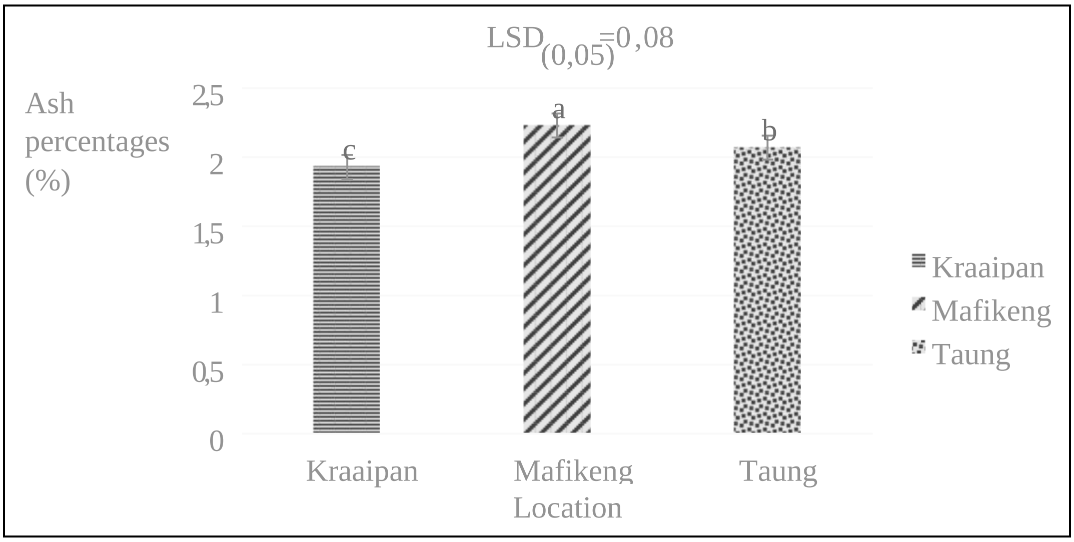

Figure 2. The influence of location on drybean ash content

As indicated in Figure 3, phosphorus fertilizer source and cultivar had no significant effect ($P \geq 0.05$) on drybean fat content. Although no significant differences in sources of phosphorus fertilizer could be found, drybean plants treated with maxi phos had a higher fat content of 2.72% than drybean plants treated with the other sources of phosphorus fertilizer. The higher fat content observed in drybean treated with maxi phos might be attributed to the water solubility and effective versatility of this phosphorus source. This observation is similar to the findings by Rugheim and Abdelgani (2012), who indicated that applications of maxi phos increased the fat content of faba bean seeds in both seasons.

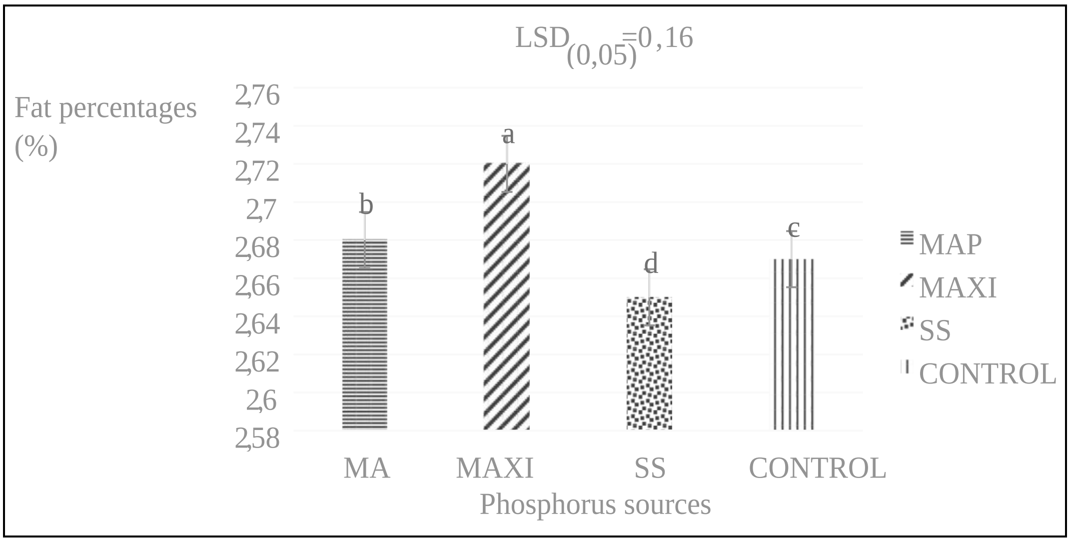

Figure 3. The influence of phosphorus fertilizer sources on drybean fat content

As shown in Figure 4, location had a significant effect ($P \leq 0.05$) on the fat content of drybean. Drybean planted at Mafikeng had a significantly higher fat content of 2.93% as compared to that planted at Kraaipan and Taung. The higher fat content observed at Mafikeng could be due to the temperature and rainfall of that location. This observation is in line with the conclusions reached by Mustiga et al. (2019), who indicated that average temperature increased the fat content of *Theobroma cacao* L beans. The interaction of treatment factors had no significant effect ($P \geq 0.05$) on the drybean fat content.

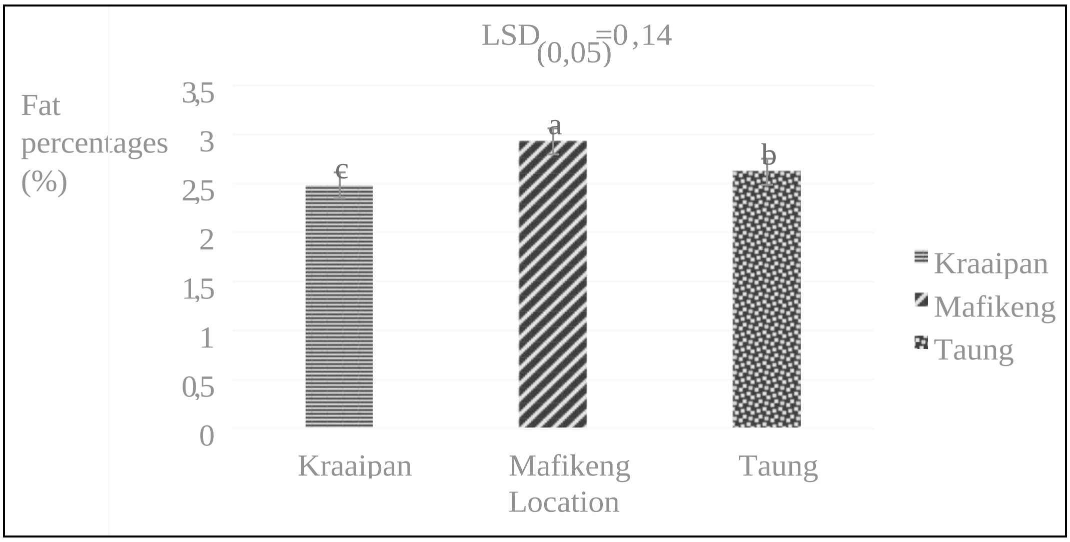

Figure 4. The influence of location on drybean fat content

CONCLUSIONS

In this study, phosphorus fertilizer sources positively affected drybean yield and seed quality. Drybean treated with monoammonium phosphate (MAP) showed higher number of pods per plant and longer pods length. Single superphosphate (SSP) and Maxi-phos produced higher seed ash and fat content respectively. The influence of cultivar contributed significantly to drybean yield in this study. Drybean cultivar PAN 148 produced longer pods length and higher seeds per pod. The variation in locations played a significant role on drybean yield and seed quality. Drybean planted at Mafikeng showed longer pods length and higher pods per plant, pods mass, ash and fat content.

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