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Accumulation of Minerals in Faba Bean Seeds and Straw in Relation to Sowing Density

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Abstract: Faba beans (*Vicia faba* L.) are a high-protein legume crop that can be widely cultivated in most climates in Europe. The amino acid composition of the faba bean protein is also beneficial for monogastric animals since it contains a great deal of lysine, an amino acid that is deficient in cereals. Two genotypes of faba beans were cultivated at three sowing densities (45, 60 and 75 seeds per m^2) during three growing seasons (years 2013–2015). The aim of the research was to assess accumulation of nutrients (N, P, K, Ca and Mg) of two faba beans in seeds and straw under different sowing densities. A field experiment was conducted in 2013–2015 at fields of Wroclaw University of Environmental and Life Sciences in southwestern Poland from which plant material was used for chemical analysis in terms of determining the accumulation of the following elements—N, P, Mg, K and Ca—in the seeds and straw. The results showed that the genotypes of the faba bean varied greatly in accumulation of nutrients in various sowing densities and in following years of research. However, the average accumulation of nitrogen, calcium and magnesium in seeds for three years (2013–2015) was significantly higher in the Bobas cultivar under 60 seeds per m^2 as well as in both tested cultivars using 75 seeds per m^2. Accumulation of potassium and phosphorus in seeds was highest in both analyzed cultivars using 60 and 75 seeds per m^2 (average for 2013–2015). Considering accumulation of elements in the straw of faba bean, it is shown that the concentration of potassium and calcium was the highest in both tested cultivars under the effect of sowing density at 60 and 75 seeds per m^2 while the concentration of nitrogen, phosphorus and magnesium did not differ significantly as an effect of the interaction of cultivar and sowing date (average for 2013–2015). Weather conditions played an important role in accumulation of nutrients of both faba bean genotypes in the years of research (2013–2015).

Keywords: faba bean; seeds; straw; accumulation; nitrogen; phosphorus; potassium; calcium; magnesium

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1. Introduction

Faba bean (*Vicia faba* L.), a nutritious legume, is widely cultivated throughout the world. China, Ethiopia, the United Kingdom, Australia and France are the major producers of this crop [1]. About 90% of faba bean production is concentrated in the Asia, European Union (EU) and Africa regions [2], and it constitutes an important crop from an ecological, nutritional and economic point of view [3].

Pulse seeds have a favorable chemical composition. The nutritional value of faba beans is lower compared to soybeans; however, they are an important source of supplementary protein in animal diets. The seeds of mature faba beans are rich in protein (26.1%), fiber (25.0%) and carbohydrates (58.3%) [4] as well as many bioactive compounds, such as total phenolics and flavors with demonstrated antioxidant activity [5].

The nutritional value of broad beans is related to their high protein content (27–34%) and depends on genotypes [6]. Most of these proteins comprise globulins (79%), albumin

(7%) and glutelin (6%) [7]. These differences also relate to the form of the faba bean. Winter forms of faba bean were found to be characterized by slightly higher concentrations of protein [8]. The chemical composition of faba beans also results from other factors, such as fertilization, growing season and location of planting [9].

In addition to proteins, faba bean is rich in complex carbohydrates, dietary fiber, choline, lecithin, minerals and secondary metabolites [10,11]. Therefore, it is a rich source of nutrients in the human diet while being low in fat and sodium and cholesterol-free [12,13].

Faba beans are a good source of macro- and micronutrients, including minerals such as sodium, calcium, potassium, copper, zinc, iron, manganese, magnesium, phosphorus and sulfur [14,15]. This nutritional value has a pivotal meaning even in human diets. High potassium (1.062 mg 100 g^{-1}) and low sodium (13 mg 100 g^{-1}) content in mature seeds of faba bean seem to be rational for people with hypertension and those on low-sodium diets. In turn, unripe faba bean seeds have higher sodium and lower potassium contents of 50 and 250 mg 100 g^{-1}, respectively [4]. According to Etemadi et al. [10], the highest concentrations of nitrogen, phosphorus, potassium, zinc and copper and protein were found in seeds.

Bioactive compounds that are traditionally classified as antinutrients in faba bean can include phytates, saponins, lectins and protease inhibitors. Although the levels of several of these compounds can be reduced or eliminated by various processing techniques, they need to be monitored because antinutritional compounds can have negative effects on the human body and reduce the digestibility of nutrients [16,17]. Advances in food technology, such as fortification, extrusion, microwave heating, fermentation, bioprocessing, etc., have generated positive results in reducing the amount of these substances for consumption. Levels of nutrients and antinutrients can vary widely between varieties of the same legume. Therefore, it is important to screen for these compounds to identify varieties that are most suitable for different uses. The antinutrients content can vary depending on the specific variety of faba beans, stage of maturity, growing climate, soil characteristics, etc. [18].

Faba bean is a promising future crop with high protein that can also provide additional environmental benefits in crop rotation in many areas of the world [19]. Crop residues are the primary source of soil organic matter supply [20,21]. They account for an average of 60% of the organic matter introduced in crop rotation. The amount of macronutrients introduced into the soil with faba bean straw will be determined in this study.

Interactions between dry matter, nutrient accumulation, remobilization and seed yield are essential to select hybrids that produce high seed yields with high nutrient content, which is pivotal for sustainable food security and nutrition [22]. Knowing the accumulation of dry matter and nutrients at different stages of growth can help to estimate dry matter and nutrient dynamics in the plant [23].

There are differences in nutrient accumulation between cultivars even under similar cultivation conditions. The amount of nutrients taken up by the crop varies according to the cultivar, yield, soil and climate conditions, plant density and management. It is always necessary to establish the accumulation value for each new cultivar released under different soil and climatic conditions [24].

Scarce information is available on accumulation of calcium, magnesium and phosphorus in seeds and straw of faba bean. Most publications concern chemical composition, taking into account protein, fat and carbohydrates in the seeds, but only few refer strictly to accumulation of minerals in seeds and straw [7,10,25,26].

Therefore, the present study was carried out to examine accumulation of nutrients (N, P, K, Ca and Mg) of two faba bean cultivars with special reference to accumulation in seeds and straw under different sowing rates.

2. Materials and Methods

2.1. Experimental Site and Soil Properties

A three-year field and laboratory experiment was conducted in 2013–2015 at fields of Wroclaw University of Environmental and Life Sciences (51°110′ N, 17°80′ E). Experiment was established using split plot design.

Directly before sowing, fertilizers were applied. It was applied 30 kg ha^{-1} N in the form of ammonium nitrate 34%, 60 kg ha^{-1} P_2O_5 in triple superphosphate 40% and 100 kg ha^{-1} K_2O in potassium salt 60%. The field was seasoned before sowing with an active tillage unit.

Two faba bean cultivars (Bobas, Granit) were allocated on the main plots and differentiated sowing density (45, 60 and 75 seeds per m^2) on the subplots. Seeds were inoculated with Nitragina (Institute of Soil Science and Plant Cultivation State Research Institute, Puławy, Poland) (an inoculant containing *Rhizobium leguminosarum* bv. *viceae* bacteria) prior to sowing. Certified seed material has been used with 100% purity and high germination capacity (80–98%) [27]. Seeds were harvested in full maturity. Yields from plots into yield per 1 ha were converted with 15% of moisture.

The soil type at the experimental site was typical brown Luvisols developed from light loam underlain by medium loam, suitable for wheat production. A soil sample for determining its chemical composition was taken prior to sowing [28]. Macronutrients availability (P and K—the Egner–Riehm method, Mg—Schachtschabel method) and soil pH (potentiometrically) in 2013 is as follows: P—very high content, K—medium content, Mg—high content. In 2014: P—very high, K—medium, Mg—high (Table 1). In turn, in 2015, the content of all analyzed elements was determined as high [29]. In each year of experiment, pH of soil was slightly acidic.

Table 1. Chemical composition of the soil during the years of research.

Years	pH in 1 M KCl	P	K	Mg
2013	5.9	62	116	87
2014	5.9	108	140	90
2015	5.9	77	176	78

2.2. Weather Conditions in Years of the Experiment

The course of weather conditions during the years of the experiment is shown in Gaussen–Walter diagrams, modified by Łukasiewicz (2006) [30], where 1 °C corresponds to 4 mm of precipitation (Figure 1). The Gaussen–Walter diagram directly represents data concerning only the levels of temperature and precipitation. It is also possible to read from it the amount of evapotranspiration and thus estimate the excess or deficiency of precipitation. If for a given month the temperature line is above the line representing the amount of precipitation, then the area below the line indicates a negative water balance—deficiency of precipitation in relation to the estimated evapotranspiration (drought period).

The course of weather conditions in 2013 was not favorable for growth and yield of faba beans. This was mainly due to low temperature in March, which resulted in postponing sowing to the second half of April. In 2013, drought occurred in April and in July and August. The course of weather conditions in 2014 was favorable for growth and yield of faba bean. In May, June and July, slight drought occurred during this period. The year 2015 was not favorable for growth and yield of faba bean. Drought was observed from April to September.

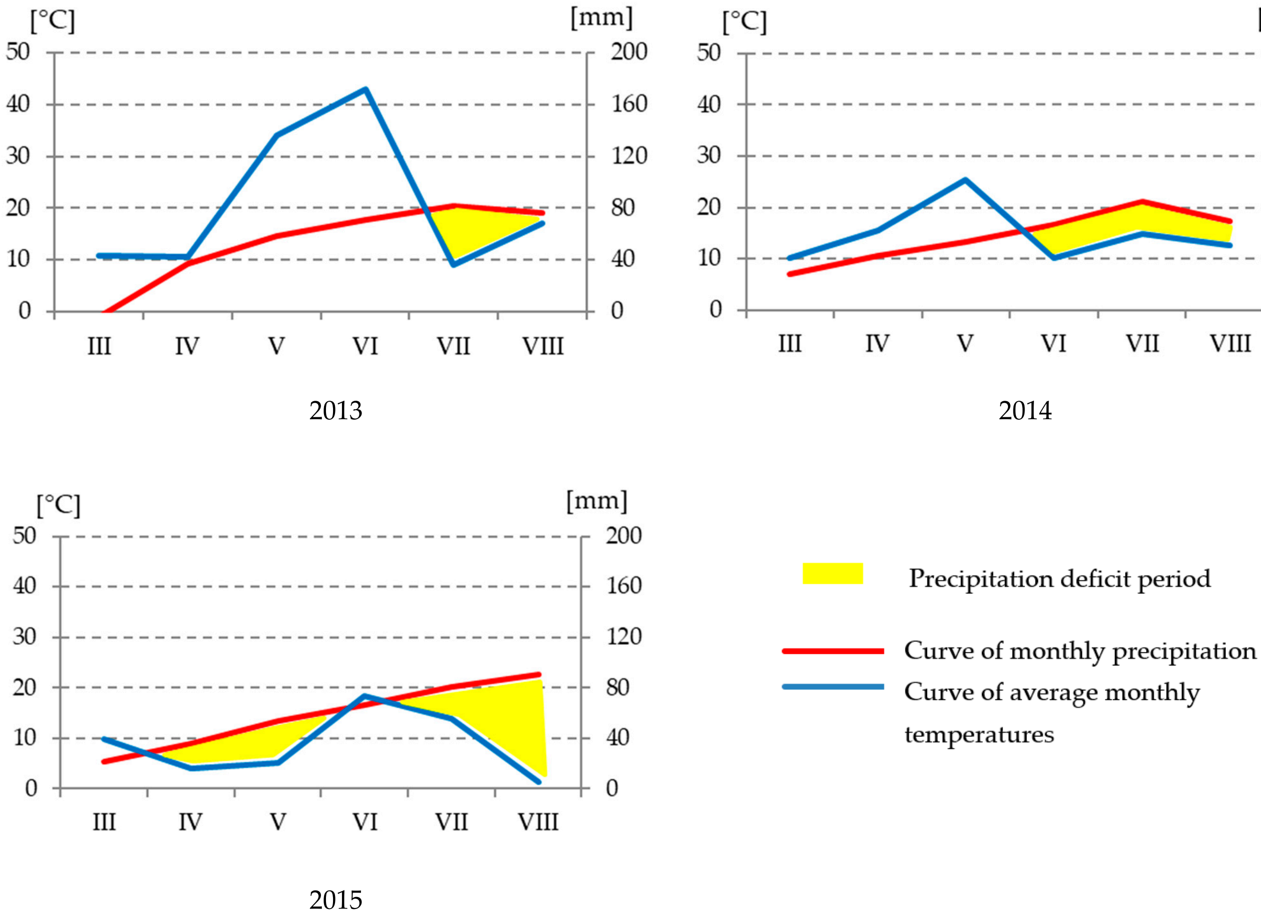

Figure 1. Gaussen–Walter diagrams modified by Łukasiewicz [30] for weather conditions in the years of research.

2.3. Chemical Analysis

After harvest, samples of seeds and straw were taken for determination of macroelements, including N, P, K, Ca and Mg content.

Accumulation of macroelements in plant material was calculated based on yield of seeds and straw and chemical content of the examined elements considering laboratory determined dry mass (4 h in 105 °C) of seeds and straw [31]. The content of macroelements in the seeds and straw was analyzed according to the following methods: nitrogen by Kjeldahl method, phosphorus by vanadomolibdate method, magnesium with titanium yellow, potassium and calcium on flame photometer (BWB Technologies UK Ltd., Newbury, UK) using flame photometry. Mineralization of plant material was completed using sulphuric acid and perhydrol in an electric furnace at 400 °C. All analyses were performed in the laboratory of Institute of Agroecology and Plant Production. Samples for laboratory analysis were taken separately from each subplot, so analyses were conducted in four repetitions.

2.4. Statistical Analyses

Analysis of variance (ANOVA) for macroelements content as well as their accumulation and seed and straw yield was completed at significance level $p < 0.05$ using Statistica program 13.1 (StatSoft, Kraków, Poland) [32]. Analysis of variance was completed for each year separately, where the factors were as follows: two cultivars, three sowing densities and four randomized replicates arranged in a split-plot design. Simultaneously analysis of variance was performed for three-year results where years were superior factor. Homogeneous groups were determined by Tukey's multiple range test using consecutive letters starting from "a"—the most beneficial value—to "d"—the least beneficial in terms of analyzed traits. Additionally, standard deviation (SD) was calculated. Figures were prepared in Excel 2010.

3. Results

3.1. Effect of Cultivar and Different Sowing Density on Yield of Seeds and Straw

Seed yield was significantly dependent on the cultivars tested, sowing density, weather conditions as well as their interactions. Significantly higher seed yield in 2013 was found in Bobas cultivar. The lowest sowing density (45 seeds per m^2) in 2013 turned out to be the least beneficial in seed yield of faba bean (Table 2). In 2014, there were no significant differences under the effect of different sowing density on seed yield. In 2015 and regarding the three-year average, the most beneficial sowing density was 75 seeds per m^2. A similar tendency was presented in interactions of factors. In both cultivars, the seeding rate in the amounts of 60 and 75 seeds per m^2 contributed to increases in seed yield in 2013 and 2015 as well as in the three-year average (Table 2).

Table 2. The effect of the examined factors on seed yields (t ha^{-1}) in the years of research 2013–2015.

Specification		Years			
		2013	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	3.57 a ± 0.22	2.51 a ± 1.18	4.07 a ± 0.36	3.40 a ± 0.95
	Granit	3.07 b ± 0.25	2.57 a ± 1.22	4.01 a ± 0.38	3.20 a ± 0.96
Sowing density	45	3.02 b ± 0.31	1.91 a ± 0.69	3.71 b ± 0.32	2.88 b ± 0.89
	60	3.46 a ± 0.23	2.30 a ± 1.32	4.00 b ± 0.10	3.25 b ± 1.04
	75	3.49 a ± 0.29	3.41 a ± 0.97	4.42 a ± 0.17	3.77 a ± 0.73
Average for interaction					
Bobas	45	3.30 b ± 0.12	1.86 a ± 0.72	3.78 b ± 0.40	2.98 ab ± 0.96
	60	3.67 a ± 0.06	2.45 a ± 1.64	4.05 ab ± 0.05	3.39 ab ± 1.12
	75	3.74 a ± 0.11	3.39 a ± 0.58	4.39 a ± 0.22	3.84 a ± 0.54
Granit	45	2.74 c ± 0.08	1.95 a ± 0.77	3.64 b ± 0.25	2.78 b ± 0.84
	60	3.25 b ± 0.02	2.16 a ± 1.16	3.94 ab ± 0.10	3.11 ab ± 0.98
	75	3.23 b ± 0.09	3.42 a ± 1.36	4.45 a ± 0.13	3.70 a ± 0.91
Average		3.32 ± 0.35	2.54 ± 1.18	4.04 ± 0.36	3.30 ± 0.96

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Straw yield did not depend significantly on the cultivar tested. The lowest straw yield was found in 2013 and 2015 using the lowest number of seeds (45 seeds per m^2) as well as in the three-year average (Table 3). Considering the interaction of factors, the highest straw yield was stated in Granit cultivar using 75 seeds per m^2 in the three-year average (Table 3).

Table 3. The effect of the examined factors on straw yields (t ha^{-1}) in the years of research 2013–2015.

Specification		Years			
		2013	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	1.91 a ± 0.21	2.24 a ± 0.99	3.09 a ± 0.38	2.41 a ± 0.79
	Granit	1.87 a ± 0.20	2.19 a ± 1.06	3.04 a ± 0.42	2.37 a ± 0.82
Sowing density	45	1.70 b ± 0.10	1.65 a ± 0.67	2.74 b ± 0.47	2.03 b ± 0.69
	60	1.95 a ± 0.13	2.10 a ± 1.02	3.10 ab ± 0.15	2.39 ab ± 0.78
	75	2.02 a ± 0.20	2.91 a ± 0.92	3.37 a ± 0.17	2.76 a ± 0.78

Table 3. *Cont.*

Specification		Years			
		2013	**2014**	**2015**	**2013–2015**
		Average for interaction			
Bobas	45	1.74 ab ± 0.13	1.71 a ± 0.72	2.90 ab ± 0.66	2.11 ab ± 0.78
	60	2.04 ab ± 0.11	2.12 a ± 1.25	3.13 ab ± 0.06	2.43 ab ± 0.83
	75	1.95 abc ± 0.24	2.89 a ± 0.73	3.25 ab ± 0.13	2.70 ab ± 0.70
Granit	45	1.67 a ± 0.05	1.59 a ± 0.71	2.56 b ± 0.12	1.94 b ± 0.60
	60	1.87 abc ± 0.09	2.09 a ± 0.96	3.07 ab ± 0.21	2.34 ab ± 0.75
	75	2.08 a ± 0.16	2.92 a ± 1.21	3.49 a ± 0.08	2.83 a ± 0.88
Average		1.89 ± 0.20	2.22 ± 1.00	3.07 ± 0.39	2.39 ± 0.80

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

The average for three years of research (2013–2015) straw yield had a dominant share in aboveground faba bean plant part yield (Figure 2).

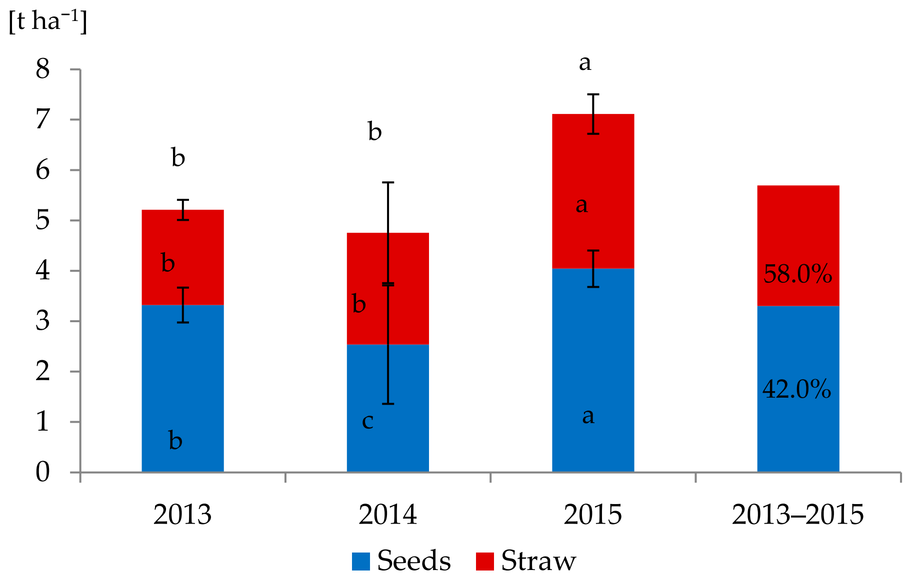

Figure 2. Aboveground faba bean plant part yield (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

The whole plant yield was highest in 2015. The same results were obtained analyzing yield of seeds and yield of straw (Figure 2).

3.2. Effect of Cultivar and Different Sowing Density on Macroelements Accumulation in Seed and Straw

Statistical analyses of macroelements content (N, P, K, Ca and Mg) in faba bean seeds and straw are presented in Tables S1–S10.

Of all the variables tested, the weather course in the study years influenced the most content of the elements analyzed in faba bean seeds (Tables S1, S3, S5, S7 and S9). Additionally, the nitrogen content in seeds was statistically lower in the Granit cultivar than in Bobas in 2014 (Table S1). The calcium content in the seeds was the most statistically variable of all essentials tested (Table S7).

The macronutrient content of the faba bean straw was strongly influenced by the conditions of the study years (Tables S2, S4, S6, S8 and S10). Nitrogen content was statistically lower in the Bobas cultivar than in Granit in 2014 and 2015 (Table S2). Among the elements analyzed, the calcium and magnesium content in faba bean straw was the most differentiated as affected by the factors examined and their interaction (Tables S8 and S10).

Due to slight statistical differences regarding macronutrients content, this paper is focused on accumulation of analyzed nutrients.

Seeds nitrogen accumulation was significantly dependent on cultivars tested, sowing density and interaction of examined factors both in the separate years of the experiment and the average in the three years of the study. Significantly higher seeds nitrogen accumulation was observed in 2013, 2015 and the 2013–2015 average in Bobas cultivar. Sowing density in the amount of 75 seeds per m^2 turned out to be the most beneficial in this case in almost all the years of the experiment (average) and in the following years of study (except 2013) (Table 4). Considering the interaction of the examined factors, this trait was the most beneficial in both cultivars in 2015 and three years of research under sowing density in the amount of 75 seeds per m^2. In 2013, Bobas and Granit characterized by the greatest seeds nitrogen accumulation was observed under 60 and 75 seeds per m^2.

Table 4. Nitrogen accumulation in the faba bean seeds (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		2013	2014	2015	2013–2015
Average for factors					
Cultivars	Bobas	151 a ± 9.5	115 a ± 52.6	136 a ± 12.2	134 a ± 34.3
	Granit	127 b ± 11.5	105 a ± 52.8	130 b ± 11.8	120 b ± 33.1
Sowing density	45	126 b ± 15.3	82 b ± 29.7	122 c ± 10.9	110 b ± 28.1
	60	145 a ± 12.2	100 ab ± 59.6	132 b ± 5.5	126 b ± 39.0
	75	146 a ± 12.3	148 a ± 41.6	145 a ± 6.0	146 a ± 24.2
Average for interaction					
Bobas	45	140 b ± 5.5	84 a ± 32.3	126 cd ± 13.3	116 bc ± 30.9
	60	157 a ± 2.5	112 a ± 75.6	136 abc ± 2.1	135 abc ± 43.8
	75	157 a ± 4.8	148 a ± 25.2	147 a ± 7.5	151 a ± 14.8
Granit	45	112 c ± 3.3	80 a ± 31.7	118 d ± 7.9	103 c ± 24.7
	60	134 b ± 1.2	87 a ± 46.2	127 bcd ± 3.4	116 bc ± 32.6
	75	136 b ± 3.9	147 a ± 58.5	143 ab ± 4.1	142 ab ± 31.1
Average		139 ± 16.0	110 ± 51.8	133 ± 12.3	127 ± 34.1

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

The tested cultivars did not differ significantly regarding straw nitrogen accumulation except in 2013. Significantly higher nitrogen accumulation in straw was found under 75 seeds per m^2 in all years of experiment as well as in the three-year study. Nitrogen accumulation in straw under interaction of examined factors was differentiated in all years of research. In 2015, the highest value of this trait was stated in Granit cultivar using 75 seeds per m^2. Statistically diverse results for nitrogen accumulation in straw were obtained in 2013. Statistically, the lowest nitrogen accumulation in straw was found in both cultivars under 45 seeds per m^2 (Bobas) and 45 and 60 seeds per m^2 (Granit). In 2014, no significant differences were found in nitrogen accumulation in the straw (Table 5).

Table 5. Nitrogen accumulation in the faba bean straw (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		2013	2014	2015	2013–2015
Average for factors					
Cultivars	Bobas	15.2 a ± 1.61	24.0 a ± 10.7	14.7 a ± 1.8	18.0 a ± 7.52
	Granit	13.7 b ± 1.38	25.4 a ± 12.1	15.8 a ± 2.1	18.3 a ± 8.64
Sowing density	45	13.4 b ± 0.88	18.3 b ± 7.4	13.9 b ± 2.1	15.2 b ± 4.84
	60	14.4 ab ± 1.74	23.4 ab ± 11.4	15.1 ab ± 0.7	17.6 ab ± 7.62
	75	15.6 a ± 1.53	32.4 a ± 10.6	16.8 a ± 1.8	21.6 a ± 9.83

Table 5. *Cont.*

Specification		2013	2014	2015	2013–2015
Average for interaction					
Bobas	45	13.8 ab ± 1.08	17.7 a ± 7.5	13.7 b ± 3.	15.1 a ± 4.71
	60	15.9 a ± 0.86	23.3 a ± 13.6	15.3 ab ± 0.3	18.2 a ± 8.08
	75	15.8 a ± 1.97	31.0 a ± 7.8	15.2 b ± 0.6	20.7 a ± 8.69
Granit	45	13.0 b ± 0.38	18.9 a ± 8.5	14.0 b ± 0.6	15.3 a ± 5.19
	60	12.9 b ± 0.66	23.5 a ± 10.8	14.9 b ± 1.0	17.1 a ± 7.45
	75	15.3 ab ± 1.20	33.8 a ± 14.0	18.4 a ± 0.4	22.5 a ± 11.17
Average		14.5 ± 1.64	24.7 ± 11.2	15.3 ± 1.99	18.1 ± 8.05

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Regarding the average for the years of study (2013–2015), nitrogen accumulation in seeds constituted the dominant share in the whole plant (87.5%) (Figure 3).

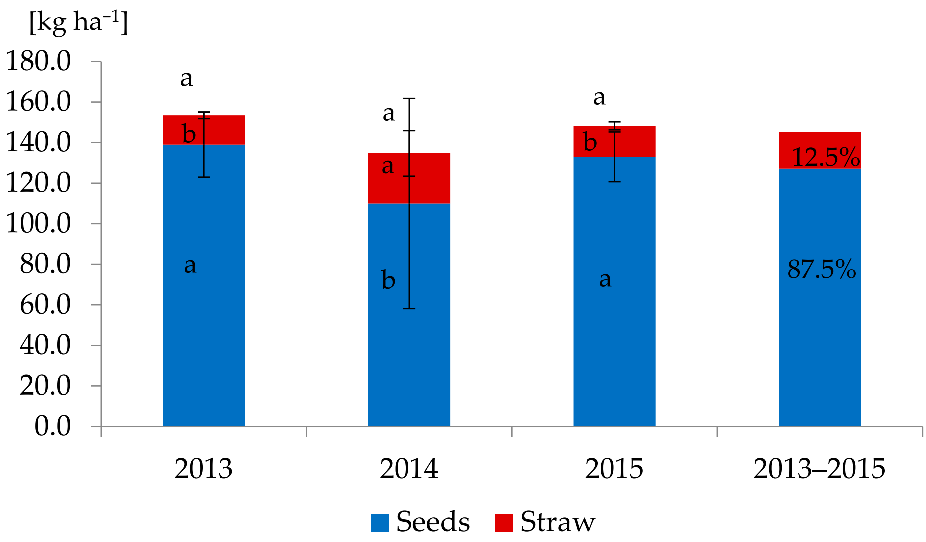

Figure 3. Nitrogen accumulation (kg ha^{-1}) in whole faba bean plant (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

Course of weather conditions in all years of research did not significantly influence nitrogen accumulation in the whole plant. Scanty rainfall in the pod-forming phase in 2014 (Figure 1) caused the lowest nitrogen accumulation in seeds. Moreover, in the same year, the highest nitrogen uptake by straw was found (Figure 3).

The examined genotypes had no significant impact on phosphorus accumulation in the seeds in 2014, 2015 and 2013–2015. Significantly higher phosphorus accumulation was observed in the seeds in 2013 related to Bobas. Sowing density in the amount of 75 seeds per m^2 was the most beneficial for accumulation of phosphorus in the seeds, while 40 seeds per m^2 caused the lowest P accumulation in the seeds (Table 6). In 2013, the greatest seeds phosphorus accumulation was found in Bobas under 75 seeds per m^2 and in Granit using 60 seeds per m^2. In the last year of study in Bobas and Granit, the most beneficial value of this trait was found using 75 seeds per m^2 and in Granit also 60 seeds per m^2. Considering the three-year average, in both cultivars, sowing density in the amount of 75 seeds per m^2 turned out to be the most positive.

Table 6. Phosphorus accumulation in the faba bean seeds (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		2013	2014	2015	2013–2015
Average for factors					
Cultivars	Bobas	17.3 a ± 2.10	11.9 a ± 5.50	11.8 a ± 1.05	13.7 a ± 4.26
	Granit	16.0 b ± 1.53	11.6 a ± 5.51	11.6 a ± 0.88	13.0 a ± 3.86
Sowing density	45	14.9 c ± 0.93	8.9 b ± 3.22	10.9 b ± 0.91	11.5 b ± 3.18
	60	17.0 b ± 0.9	10.8 ab ± 6.22	11.5 b ± 0.27	13.1 b ± 4.47
	75	18.1 a ± 2.14	15.6 a ± 4.39	12.7 a ± 0.49	15.4 a ± 3.4
Average for interaction					
Bobas	45	15.6 c ± 0.59	8.6 a ± 3.31	11.0 b ± 1.18	11.7 b ± 2.09
	60	16.4 c ± 0.26	11.5 a ± 7.71	11.6 abc ± 0.12	13.2 ab ± 1.53
	75	20.1 a ± 0.61	15.6 a ± 2.64	12.8 a ± 0.62	16.2 a ± 5.50
Granit	45	14.1 d ± 0.41	9.2 a ± 3.62	10.8 b ± 0.72	11.4 b ± 5.51
	60	17.6 b ± 0.12	10.1 a ± 5.43	11.3 ab ± 0.29	13.0 ab ± 1.05
	75	16.2 c ± 0.43	15.5 a ± 6.15	12.6 ab ± 0.38	14.7 ab ± 0.89
Average		16.7 ± 1.93	11.8 ± 5.39	11.7 ± 0.96	13.4 ± 4.05

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

No significant differences were observed in straw phosphorus accumulation under the tested genotypes. Further, 75 seeds per m^2 was considered the most rational in straw phosphorus accumulation in 2014, 2015 and in the overall three-year study. An exception was 2013, with the greatest straw phosphorus accumulation using 60 seeds per m^2. The effect of interaction of examined factors varied in the years of research. In 2013, the greatest straw phosphorus accumulation in Bobas cultivar was found under 60 seeds per m^2 and 60 and 75 seeds per m^2 in Granit cultivar. In 2015, the lowest value of phosphorus accumulation in straw was stated in Bobas using 75 seeds per m^2 and 60 and 75 seeds per m^2 in Granit cultivar (Table 7).

Table 7. Phosphorus accumulation in the faba bean straw (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		2013	2014	2015	2013–2015
Average for factors					
Cultivars	Bobas	2.35 a ± 0.31	3.12 a ± 1.42	1.24 a ± 0.16	2.24 a ± 1.13
	Granit	2.31 a ± 0.13	3.07 a ± 1.43	1.25 a ± 0.20	2.21 a ± 1.11
Sowing density	45	2.15 b ± 0.15	2.32 b ± 0.94	1.15 b ± 0.19	1.87 b ± 0.75
	60	2.47 a ± 0.21	2.89 ab ± 1.42	1.17 b ± 0.05	2.18 ab ± 1.09
	75	2.36 ab ± 0.23	4.07 a ± 1.29	1.42 a ± 0.11	2.62 a ± 1.33
Average for interaction					
Bobas	45	2.07 b ± 0.16	2.25 a ± 0.95	1.20 b ± 0.28	1.84 a ± 0.31
	60	2.63 a ± 0.14	2.98 a ± 1.74	1.33 b ± 0.02	2.27 a ± 0.13
	75	2.36 ab ± 0.29	4.13 a ± 1.04	1.09 ab ± 0.06	2.60 a ± 1.42
Granit	45	2.24 b ± 0.07	2.39 a ± 1.07	1.15 b ± 0.05	1.90 a ± 1.43
	60	2.32 ab ± 0.12	2.80 a ± 1.28	1.51 b ± 0.08	2.09 a ± 0.16
	75	2.37 ab ± 0.18	4.02 a ± 1.67	1.20 a ± 0.04	2.64 a ± 0.20
Average		2.33 ± 0.23	3.10 ± 1.40	1.25 ± 0.18	2.22 ± 1.11

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Regarding the average for the years of study (2013–2015), phosphorus accumulation in seeds constituted the dominant share in the whole plant (85.7%) (Figure 4).

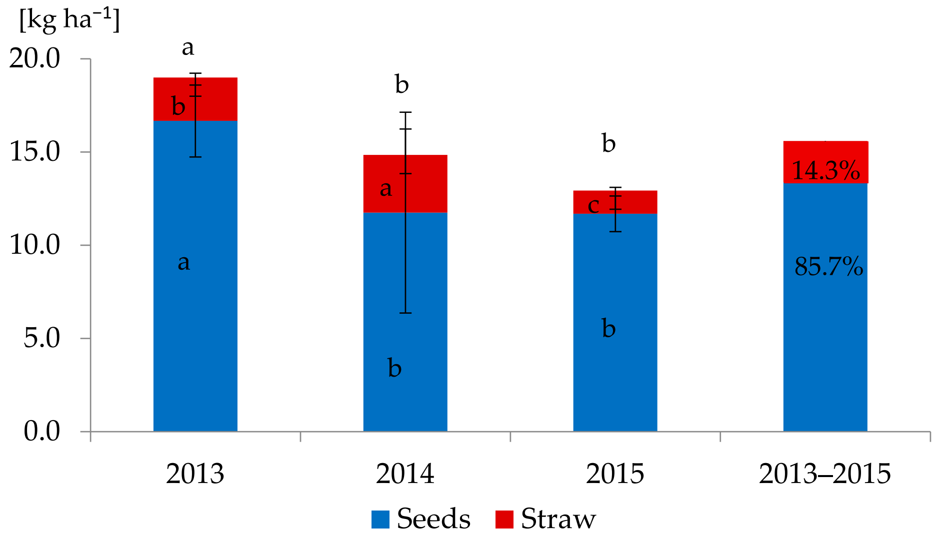

Figure 4. Phosphorus accumulation kg ha^{-1} in whole faba bean plant (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

The highest phosphorus accumulation in the whole plants was found in 2013. The greatest phosphorus accumulation in the seeds was determined in 2013, while phosphorus accumulation in straw was differentiated in the years of the study (Figure 4).

Genotypes had no significant effect on seeds potassium accumulation in the years of research except 2013, where Bobas was found to have more potassium in the seeds (Table 8). The highest sowing density significantly affected the abovementioned trait in all years of research. Taking into account the interaction of the examined factors, a trend has been established: using 75 seeds per m^2 in both cultivars in 2013, 2015 and the three-year study caused an increase in phosphorus accumulation in straw.

Table 8. Potassium accumulation in the faba bean seeds (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		**2013**	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	35.4 a ± 2.4	23.9 a ± 11.0	36.7 a ± 3.2	32.0 a ± 8.8
	Granit	31.2 b ± 2.3	23.5 a ± 11.2	36.3 a ± 3.2	30.3 a ± 8.5
Sowing density	45	30.5 c ± 2.8	18.2 b ± 6.7	33.4 c ± 2.9	27.4 b ± 8.0
	60	33.8 b ± 1.5	21.4 ab ± 12.3	36.5 b ± 0.7	30.6 b ± 9.6
	75	35.5 a ± 2.9	31.6 a ± 8.9	39.6 a ± 1.5	35.6 a ± 6.2
Average for interaction					
Bobas	45	33.0 c ± 1.2	17.3 a ± 6.7	34.2 b ± 3.7	28.2 bc ± 9.0
	60	35.2 b ± 0.5	22.8 a ± 15.3	36.3 ab ± 0.5	31.4 abc ± 10.2
	75	38.1 a ± 1.2	31.6 a ± 5.3	39.7 a ± 2.0	36.5 a ± 4.8
Granit	45	28.1 d ± 0.9	19.0 a ± 7.5	32.7 b ± 2.2	26.6 c ± 7.2
	60	32.5 c ± 0.2	20.1 a ± 10.8	36.7 ab ± 1.0	29.7 abc ± 9.3
	75	32.9 c ± 0.9	31.6 a ± 12.5	39.5 a ± 1.2	34.6 ab ± 7.5
Average		33.3 ± 3.2	23.7 ± 10.9	36.5 ± 3.2	31.2 ± 8.0

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Genotypes had no significant effect on straw potassium accumulation in all years of research (Table 9). Sowing density in the amount of 75 seeds per m^2 contributed to increased straw potassium accumulation in 2014, 2015 and three years of research and 60 and 75 seeds per m^2 in 2013. Straw potassium accumulation varied significantly under interaction of the examined factors in the years of study. In 2013 and 2015 in Bobas cultivar, higher sowing rates (60 and 75 seeds per m^2) were the most beneficial in straw potassium accumulation. Taking into account the three years of research results, 75 seeds per m^2 in both cultivars increased straw potassium accumulation.

Table 9. Potassium accumulation in the faba bean straw (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		2013	2014	2015	2013–2015
Average for factors					
Cultivars	Bobas	29.6 a ± 3.6	32.7 a ± 14.2	59.5 a ± 7.6	40.6 a ± 16.5
	Granit	28.3 a ± 3.4	29.0 a ± 14.5	60.0 a ± 7.5	39.1 a ± 17.7
Sowing density	45	25.4 b ± 1.5	22.9 b ± 9.8	53.4 b ± 8.6	33.9 b ± 15.9
	60	29.9 a ± 2.3	28.6 ab ± 14.0	60.1 ab ± 2.8	39.5 b ± 16.9
	75	31.5 a ± 3.0	41.1 a ± 12.9	65.7 a ± 3.1	46.1 a ± 16.5
Average for interaction					
Bobas	45	26.0 b ± 2.0	26.0 a ± 11.0	55.3 ab ± 12.6	35.7 bc ± 16.9
	60	31.6 a ± 1.7	29.5 a ± 17.2	59.7 ab ± 1.1	40.2 abc ± 17.0
	75	31.2 a ± 3.9	42.8 a ± 10.7	63.5 ab ± 2.6	45.8 ab ± 15.3
Granit	45	24.8 b ± 0.7	19.8 a ± 8.9	51.5 b ± 2.4	32.0 c ± 15.3
	60	28.2 ab ± 1.4	27.8 a ± 12.8	60.6 ab ± 4.2	38.9 abc ± 17.5
	75	31.9 a ± 2.5	39.5 a ± 16.4	67.9 a ± 1.6	46.4 a ± 18.4
Average		29.0 ± 3.5	30.9 ± 14.2	59.8 ± 7.4	39.8 ± 17.0

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Regarding the average in the three-year research (2013–2015), potassium accumulation in seeds constituted 56.1% and straw 43.9% (Figure 5).

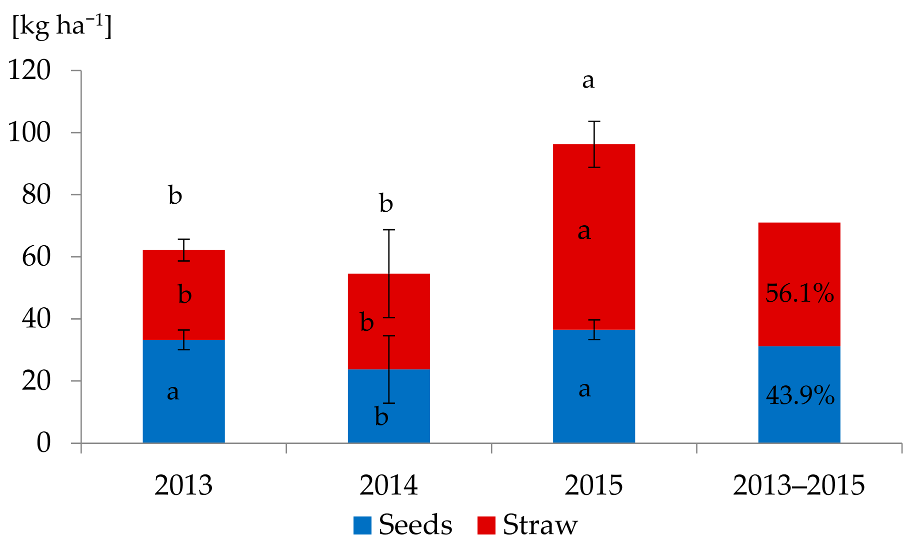

Figure 5. Potassium accumulation (kg ha^{-1}) in whole faba bean plant (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

The highest potassium accumulation in the whole plants was noted in 2015. The greatest potassium accumulation in the seeds was found in 2013 and 2015 and in the straw 2013 and 2014 (Figure 5).

Calcium accumulation in the seeds depended on genotypes and sowing density in the years of experiment. Its accumulation in 2013 and the three-year research study showed that Bobas is characterized by higher values of this trait. Sowing density in the amount of

75 seeds per m^2 contributed to increased calcium accumulation in the seeds in 2015. Regarding the three-year study results, the same tendency as in 2015 was observed (Table 10). In the first year of research, 60 seeds per m^2 turned out to be the most beneficial. The interaction of experience factors in the 2013, 2015, and three-year study periods significantly modified seeds calcium accumulation. In the first year of research, higher sowing density (60 and 75 seeds per m^2 in Bobas and 60 seeds per m^2 in Granit) in both cultivars caused increased calcium accumulation in the seeds. In 2015, Bobas under 75 seeds per m^2 increased calcium accumulation in the seeds. In the three-year data results, 75 seeds per m^2 in both cultivars contributed to calcium accumulation in the seeds (Table 10).

Table 10. Calcium accumulation in the faba bean seeds (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		**2013**	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	3.95 a ± 0.37	1.75 a ± 0.80	4.69 a ± 0.58	3.46 a ± 1.40
	Granit	2.95 b ± 0.27	1.67 a ± 0.73	4.83 a ± 0.48	3.15 b ± 1.41
Sowing density	45	3.09 c ± 0.41	1.39 a ± 0.52	4.15 c ± 0.37	2.88 b ± 1.23
	60	3.75 b ± 0.47	1.52 a ± 0.88	4.90 b ± 0.09	3.39 a ± 1.53
	75	3.52 a ± 0.73	2.21 a ± 0.61	5.23 a ± 0.21	3.65 a ± 1.38
Average for interaction					
Bobas	45	3.47 b ± 0.13	1.29 a ± 0.50	4.01 a ± 0.43	2.92 cd ± 1.28
	60	4.19 a ± 0.07	1.62 a ± 1.08	4.90 a ± 0.06	3.57 ab ± 1.58
	75	4.20 a ± 0.12	2.33 a ± 0.39	5.16 b ± 0.26	3.90 a ± 1.25
Granit	45	2.72 c ± 0.08	1.50 a ± 0.59	4.28 b ± 0.29	2.83 d ± 1.24
	60	3.31 b ± 0.02	1.43 a ± 0.77	4.90 b ± 0.13	3.21 cd ± 1.54
	75	2.84 c ± 0.08	2.09 a ± 0.82	5.30 b ± 0.15	3.41 abc ± 1.50
Average		3.45 ± 0.60	1.71 ± 0.75	4.76 ± 0.52	3.31 ± 1.40

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

In turn, calcium accumulation in the straw depended on genotypes in the years of study only in 2013 and 2015. In 2013, Bobas cultivar was characterized by higher calcium accumulation in the straw and in 2015 Granit (Table 11). Sowing density modified this trait in 2014, 2015 and in the three-year experiment. Significantly higher values of this trait concerned the highest sowing density. An interaction of factors shaped this trait under study in 2013, 2015 and the three years of the study. In the first year of study, Granit cultivar was characterized by significantly greater value under 45 and 75 seeds per m^2. The same tendency was observed in both cultivars in the three years of research using the highest sowing density.

Table 11. Calcium accumulation in the faba bean straw (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		**2013**	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	12.7 a ± 1.37	9.1 a ± 3.99	30.2 b ± 3.74	17.3 a ± 9.86
	Granit	11.1 b ± 1.04	8.5 a ± 4.18	33.0 a ± 4.24	17.5 a ± 11.64
Sowing density	45	11.5 a ± 0.63	6.4 b ± 2.63	28.3 b ± 4.37	15.4 c ± 9.96
	60	11.7 a ± 1.98	8.6 ab ± 4.23	32.0 ab ± 2.58	17.4 b ± 11.03
	75	12.4 a ± 1.40	11.5 a ± 3.63	34.4 a ± 3.04	19.4 a ± 11.18

Table 11. *Cont.*

Specification		2013	2014	2015	2013–2015
Average for interaction					
Bobas	45	11.5 ab ± 0.90	6.9 a ± 2.91	28.6 b ± 6.52	15.7 bc ± 10.47
	60	13.5 a ± 0.74	9.0 a ± 5.23	30.1 b ± 0.55	17.5 abc ± 9.90
	75	13.0 a ± 1.64	11.5 a ± 2.68	31.8 ab ± 1.32	18.8 ab ± 9.81
Granit	45	11.5 ab ± 0.31	5.9 a ± 2.66	27.9 b ± 1.28	15.1 bc ± 9.88
	60	9.9 b ± 0.48	8.2 a ± 3.75	34.0 ab ± 2.31	17.4 abc ± 12.50
	75	11.8 ab ± 0.95	11.4 a ± 4.74	37.1 a ± 0.92	20.1 a ± 12.81
Average		11.9 ± 1.44	8.8 ± 4.01	31.6 ± 4.17	17.4 ± 10.71

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Dominant calcium accumulation was observed in straw (84.0%) considering the average for the three-year study (2013–2015) (Figure 6).

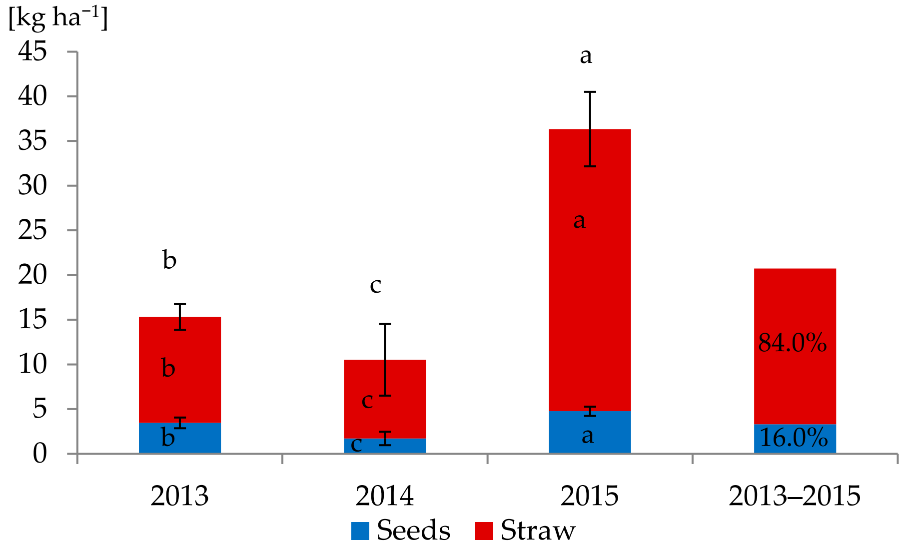

Figure 6. Calcium accumulation (kg ha^{-1}) in whole faba bean plant (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

Calcium accumulation in the whole plants was statistically varied in the years of study. Both in the seeds and straw, the highest calcium accumulation was observed in 2015 and the lowest in 2014 (Figure 6).

Magnesium accumulation in seeds depended on all the examined factors in the years of research as well as on their interaction. Significantly higher magnesium accumulation in seeds was observed in 2013, 2015 and the three-year study in Bobas cultivar (Table 12). In 2013 and 2015, 60 and 75 seeds per m^2 increased the magnesium accumulation in the seeds. Observing the interaction of factors, a similar tendency occurred: 2015 and three-years of study showed the highest value of seeds magnesium accumulation in both cultivars under 75 seeds per m^2. In turn, in 2013 in both cultivars, higher sowing density (60 and 75 seeds per m^2) contributed to higher value of this element accumulation.

Table 12. Magnesium accumulation in the faba bean seeds (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		**2013**	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	3.52 a ± 0.17	2.60 a ± 1.19	5.35 a ± 0.43	3.82 a ± 1.36
	Granit	2.86 b ± 0.20	2.38 a ± 1.08	5.09 b ± 0.42	3.44 b ± 1.37
Sowing density	45	2.96 b ± 0.40	1.97 a ± 0.72	4.83 b ± 0.46	3.25 b ± 1.32
	60	3.27 a ± 0.36	2.26 a ± 1.34	5.23 a ± 0.14	3.59 b ± 1.48
	75	3.33 a ± 0.32	3.23 a ± 0.90	5.60 a ± 0.24	4.05 a ± 1.24
Average for interaction					
Bobas	45	3.33 b ± 0.12	1.90 a ± 0.73	5.03 bc ± 0.54	3.42 b ± 1.42
	60	3.61 a ± 0.06	2.51 a ± 1.68	5.32 ab ± 0.07	3.82 ab ± 1.49
	75	3.62 a ± 0.11	3.39 a ± 0.58	5.70 a ± 0.28	4.23 a ± 1.14
Granit	45	2.60 d ± 0.08	2.05 a ± 0.81	4.63 c ± 0.31	3.09 b ± 1.25
	60	2.94 c ± 0.02	2.01 a ± 1.08	5.14 abc ± 0.14	3.36 b ± 1.49
	75	3.04 c ± 0.08	3.07 a ± 1.21	5.50 ab ± 0.16	3.87 ab ± 1.36
Average		3.19 ± 0.38	2.49 ± 1.12	5.22 ± 0.44	3.63 ± 1.37

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Straw magnesium accumulation depended on genotype, sowing density and its interaction in the years of research under different weather conditions (Table 13). Bobas was characterized by statistically greater magnesium accumulation in straw in 2013 and in the three-year study. The three-year experiment's results showed an impact of the highest sowing density on magnesium accumulation as well as in 2013. Analyzing the interaction of factors, in 2013 and 2015, magnesium accumulation in the straw in both cultivars increased under increasing sowing density to 75 seeds per m^2.

Table 13. Magnesium accumulation in the faba bean straw (kg ha^{-1}) as influenced by the examined factors during the study years 2013–2015.

Specification		**2013**	**2014**	**2015**	**2013–2015**
Average for factors					
Cultivars	Bobas	2.58 a ± 0.29	5.33 a ± 2.26	4.66 a ± 0.58	4.19a ± 1.77
	Granit	2.04 b ± 0.20	4.84 a ± 2.10	4.56 a ± 0.68	3.82 b ± 1.78
Sowing density	45	2.16 b ± 0.23	4.09 a ± 1.67	4.07 b ± 0.75	3.44 b ± 1.37
	60	2.36 ab ± 0.52	4.92 a ± 2.41	4.67 a ± 0.22	3.98 ab ± 1.80
	75	2.41 a ± 0.29	6.24 a ± 1.98	5.09 a ± 0.26	4.58 a ± 1.98
Average for interaction					
Bobas	45	2.35 bc ± 0.18	4.30 a ± 1.82	4.39 ab ± 1.00	3.68 a ± 1.47
	60	2.83 a ± 0.16	5.00 a ± 2.93	4.69 ab ± 0.09	4.17 a ± 1.83
	75	2.56 ab ± 0.32	6.68 a ± 1.68	4.89 a ± 0.20	4.71 a ± 1.98
Granit	45	1.98 cd ± 0.06	3.89 a ± 1.75	3.76 b ± 0.17	3.21 a ± 1.29
	60	1.89 d ± 0.09	4.83 a ± 2.22	4.65 ab ± 0.32	3.79 a ± 1.83
	75	2.26 bcd ± 0.18	5.81 a ± 2.41	5.28 a ± 0.13	4.45 a ± 2.06
Average		2.31 ± 0.37	5.09 ± 2.15	4.61 ± 0.62	4.01 ± 1.78

± means SD for the average for factors and factor interactions in each study year and the three-year mean. Different letters indicate a significant difference (Tukey's multiple range test).

Higher magnesium accumulation was observed in seeds (52.4%) compared to straw (47.6%) considering the average for the three-year research (2013–2015) (Figure 7).

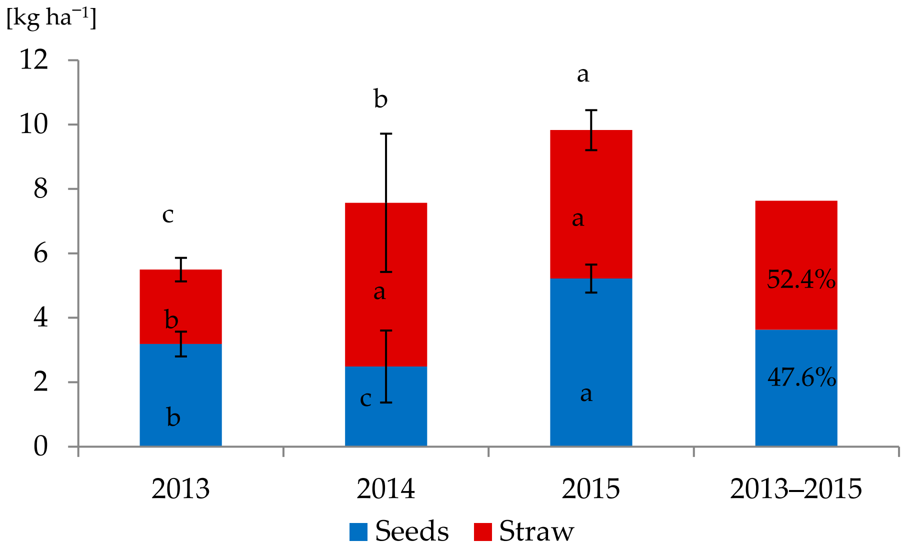

Figure 7. Magnesium accumulation (kg ha^{-1}) in whole faba bean plant (average for years). The vertical line atop bar is SD for that mean. Different letters indicate a significant difference (Tukey's multiple range test).

Magnesium accumulation in whole plants as well as in seeds diverged in the years of research; the highest was observed in 2015 (Figure 7). The greatest accumulation of magnesium in straw was noted also in 2015 and additionally in 2014 (Figure 7).

4. Discussion

No straw yield variations between cultivars were observed for faba bean in all years of research; however, taking into account seed yield, statistical differences were observed in the first year of study. Different sowing density caused differences both in seed and straw yield in 2013 and 2015 in our study. The considerably lower seed yield of faba bean using 45 seeds per m^2 in 2013 and 45 and 60 seeds per m^2 in 2015 as well as average in years 2013–2015 was observed. Seed yield of faba bean is very sensitive to water stress, especially during flowering and pod filling [33]; therefore, the lowest seed yield was found in 2013 and 2014.

Our study presented that seed and straw elements content in faba bean was affected by numerous factors, such as varieties, sowing density and weather conditions. Our results are consistent with the results for other studies where the weather conditions, cultivars and their interaction are predominant factors for macroelements content. According to Alghmadi [34], Muktadir et al. [35], Etemadi et al. [10] and Khazaei and Vanderberg [19], chemical composition of the seeds was strictly dependent on genetic variation as well as in our study nitrogen accumulation in the seeds and straw. In our study, statistical analysis revealed significant differences within the cultivars. In our research, the highest nitrogen accumulation was observed in 2013, 2015 and the three-year study of Bobas cultivar (Table 2). In the research of Olle and Tam [36], different genotypes affected the nitrogen content of faba bean in the years of the study. The highest content of nitrogen was observed in Gloria cultivar and the lowest in Bauska and Jõgeva cultivar. On the basis of their study, amount of sowing had no effect on the nitrogen content in both years, contrary to our study (Table 1). In turn, in Etemadi et al. [10], the highest nitrogen concentration was analyzed in Windsor cultivar with 3.47%, followed by Delle Cascine with 3.43%, while the lowest nitrogen concentration in seeds was detected in Early Violletto cultivar with 2.71%. The abovementioned research and our study suggest that nitrogen accumulation is strongly dependent on genetic properties and weather conditions, especially from water deficits occurring in the vegetation period.

According to Neugschwandtner et al. [37], no significant differences in seed nitrogen concentrations between years were found, as well as in our study (Table S1). Nitrogen concentration in straw was, in their research, higher in a dry year because drought reduced seed yield and nitrogen remobilization from vegetative parts of plants to seed [38], as well as in our research (Table S2). Nitrogen-rich crop residues are the reason for the good pre-cropping effect of faba bean, as well as in our research.

Average nitrogen uptake by seed (117–300 kg N ha^{-1}) and phosphorus uptake by seed (34–82 kg P_2O_5 ha^{-1}) were generally dependent on the soil and environmental conditions of the site location [39,40]. According to Barłóg and Łukowiak [40], total nitrogen accumulation was 176.3–189.4 kg N ha^{-1} depending on the year. In our study, nitrogen accumulation was also dependent on the year of the study. According to Turpin et al. [41], faba bean accumulated a total of 209–275 kg N ha^{-1}, whereas, in Allito et al. [42], the amount was about 194.7–309.6 kg N ha^{-1}. In our study, the maximum value was around 151 kg ha $^{-1}$ in the seeds of Bobas cultivar and 25.4 kg ha^{-1} (Table 4) in the straw of Granit cultivar (Table 5).

According to Etemadi et al. [10], the highest concentrations of elements such as nitrogen and phosphorus were observed in the seeds, as well as in our study (Tables S1–S4). The same authors claimed that the highest potassium content was found in the seeds, while, in our study, it was in the straw (Tables S5 and S6). The greatest calcium and magnesium content was found in the straw in our study, as well as in Etemadi et al. [10] (Tables S7–S10).

A study by Olle and Tamm [36] showed that phosphorus content varied among faba bean cultivars. Similarly, Hossain and Mortuza [7] found that phosphorus content varies among varieties, while high phosphorus content is needed especially for good root growth [43]. In our study, the highest content of phosphorus in the seeds concerned Bobas cultivar only in 2013 (Table 6). In all years of study, the greatest phosphorus content was stated using 75 seeds per m^2.

Faba bean seeds are rich in macroelements, such as potassium, calcium and magnesium, which is demonstrated by Khazaei and Vanderberg [19].

In Muktadir et al.'s [35] study, potassium was observed to be at the highest concentration followed by calcium and magnesium in leaf samples and seeds. In the conducted experiment, the same tendency was observed in seeds K > Mg > Ca (Tables S5, S7 and S9). Potassium also dominated in straw, but the relation of Mg and Ca content is different (Ca > Mg) (Tables S6, S8 and S10).

In our study, there were no cultivar differences in all years of research. Different results were found by Olle and Tamm [36]. In their research, in 2015, the highest potassium content was in cultivars Gloria and Jõgeva, while, in 2016, the highest potassium content was characterized by the cultivar Gloria. In their study, sowing density affected the potassium content in the seeds. Sowing density in their research had an important effect in 2016 in the amount of 36 seeds per m^2 and decreased the potassium content in varieties Gloria, Julia and Lielplatones. In our study, sowing density had no significant impact on potassium content (Table S5).

According to Etemadi et al. [10], lower content of magnesium and calcium was stated in seeds, as well as in our study (Tables S8 and S10). In research by Olle and Tam [36] and Hossain and Mortuza [7], calcium content depended on genotypes. The highest calcium content was related to variety Bauska. In 2015, the lowest calcium content was reported in the variety Lielplatones, while, in 2016, the lowest Ca content was characterized by cultivar Gloria. In our study, cultivar differences were observed only in 2013 (Table S7). Bobas cultivar had statistically the highest content of calcium in the seed (Table S7).

In our study, the highest calcium accumulation in the seeds and straw concerned Bobas variety in 2013 and in straw in 2015 in Granit cultivar. In our study, sowing density had an impact on calcium accumulation in the seeds. The highest accumulation was observed under 75 seeds per m^2 as well as in straw (Tables 10 and 11). Higher calcium content is beneficial because it reduces insect and disease attacks and increases transportability and storage quality [44].

Different genotypes affected magnesium content in the seeds in faba bean in both years (2013 and 2015) as well as in Cakmak's [45] study. A higher magnesium content may be desirable as higher magnesium limits the occurrence of insect pests and diseases [42]. In Olle and Tamm [36], the highest content of magnesium was found in cultivar Gloria, while the lowest Mg content was characteristic of cultivar Jõgeva. In our study, the greatest magnesium accumulation in the seeds was stated in Bobas cultivar as well as in straw (only in 2013) (Tables 12 and 13). Amount of seeding had no effect on magnesium content in the seeds only in 2014 (Table 9). Olle an Tamm [36] stated that seeding rate affected magnesium content in 2016. The higher sowing norm increased the magnesium content in Gloria and Jõgeva varieties. In our study, sowing density influenced magnesium accumulation in the seeds. Higher sowing (60 and 75 seeds per m^2) in 2013 and 2015 caused increased magnesium accumulation in the seeds as well as 75 seeds per m^2 in three years of study (Tables 12 and 13).

Chemical composition is a highly heritable factor. In Khazaei and Vanderberg [19], estimates of heritability of mineral intake were medium to high. Higher heritability was found for calcium and magnesium. The high heritability found for faba bean suggested that genetic improvement in chemical composition is possible to perform.

According to Khazaei and Vanderberg [19], interaction of environment (location) and genotypes was significant for most elements except magnesium, as well as in our study (magnesium in straw and calcium in seeds). In our research, Granit cultivar in 2013 and 2015 was characterized by the highest magnesium accumulation under 60 and 75 seeds per m^2.

Faba bean, as other legumes, is sensitive to changing agroclimatic conditions. Constant genotype traits may be changed by unfavorable agroecosystems compounds [46]. This phenomenon, as well as climate change and increasing costs of crop production, are forcing producers to improve agricultural practices in legumes cultivation. Therefore, it is important to adjust sowing density and cultivars to local conditions.

5. Conclusions

Use of two cultivars and different sowing densities affected nutrients accumulation. In the present study, the tested cultivars were characterized by a differentiated accumulation of macroelements. The Bobas cultivar accumulated more by 11.7% N and more by 9.8% Ca in seeds, as well as more Mg in seeds and straw (by 11.0% and 9.7%, respectively) than Granit cultivar. N accumulation is closely related to protein accumulation, so, among the cultivars tested, Bobas is recommended for cultivation under the climatic conditions of southwestern Poland. Higher sowing densities generally contributed to higher nitrogen, phosphorus, potassium, calcium and magnesium accumulation in the seeds and straw, which was directly related to greater seed and straw yield. The interaction of cultivars and sowing density (2013–2015 average) showed that, for the highest accumulation of all macronutrients studied in seeds, the combination of Bobas cv. and sowing of 60 seeds per m^2 was the most favorable. The highest sowing density studied did not contribute to the greatest accumulation of elements in both cultivars, and, since pulse seed material is expensive, according to this research, it is not recommended to sow 75 seeds per m^2. However, our study confirmed that legumes are sensitive to variable thermal and humidity conditions, and yielding and chemical composition of seeds and straw are strongly dependent on the course of weather conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13010147/s1, Table S1: Nitrogen content in the faba bean seeds (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S2: Nitrogen content in the faba bean straw (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S3: Phosphorus content in the faba bean seeds (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S4: Phosphorus content in the faba bean straw (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S5: Potassium content in the faba bean seeds (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S6: Potassium content in the faba bean straw (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S7: Calcium content in the faba bean seeds (g kg^{-1}) as influenced by the examined factors during the study years

2013–2015; Table S8: Calcium content in the faba bean straw (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S9: Magnesium content in the faba bean seeds (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015; Table S10: Magnesium content in the faba bean straw (g kg^{-1}) as influenced by the examined factors during the study years 2013–2015.

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