Research on the content and distribution of macronutrients (NPK) in different plant components of *Sorghum bicolor* (L.) Moench grown at A.R.D.S Secuieni

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Abstract. Due to its yield potential in restrictive climatic and soil conditions (poor soils, high temperatures, reduced rainfall), grain sorghum acquired agronomic importance in developed countries where the grains are used mainly as fodder, but also as human food, mostly for gluten-free products. Thereby, knowing the chemical composition of grain sorghum (*Sorghum bicolor* var. *Eusorghum*) is essential for processing the plants as food or feed. The purpose of this research was to identify the content of macronutrients in the vegetative organs and grains of eight grain sorghum hybrids (Alimentar, Kalatur, Elan, Armorik, Albanus, Arsky, Foehn, and Shamal). Grains nitrogen (N) varied between 1.29% and 1.66%, phosphorus (P) was between 0.26% and 0.33%, and potassium (K) ranged from 0.46% to 0.61%. Concerning the concentration of macronutrients in the vegetative organs, the following values were obtained: N between 0.28% (stem) and 1.19% (leaves), P from 0.3% (stem) to 0.14% (leaves) and K between 1.07% (panicle) and 6.08% (stem). Alimentar hybrid stood out compared to other hybrids in terms of higher grain and above-ground dry biomass yields but also regarding plants macronutrients content (NPK g plant^{-1}). Thus, this hybrid obtained a grain yield of 98.6 g plant^{-1} and a total dry matter yield of 82.6 g plant^{-1}, of which 37.4 g plant^{-1} represented the stem's dry matter, 28.7 g plant^{-1} was leaves' dry matter, and 16.6 g plant^{-1} was the dry matter of the panicle. The quantity of macronutrients in Alimentar hybrid had the following values: N between 0.09 g plant^{-1} (panicle) and 1.53 g plant^{-1} (grains), P from 0.016 g plant^{-1} (stem) to 0.32 g plant^{-1} (grains), and K between 0.23 g plant^{-1} (panicle) and 2.03 g plant^{-1} (stem).
Key Words: sorghum yield, stem, leaf, macronutrients, nitrogen, phosphorus, potassium.

Introduction. Grain sorghum, a species specific to the arid and dry climate, found mainly in developing countries in Asia and Africa, has become a crop of interest in developed countries. Due to its nutritional and agronomic properties, it is used as fodder or as a gluten-free food resource and even as a raw material in some manufacturing industries. In developing countries, grain sorghum is a staple food (Rhodes 1995; Mafongoya et al 2006; Buah et al 2012), and the sorghum crop is vital in these areas due to the rapid population growth (Turner & Rao 2013).

Grain sorghum crop (*Sorghum bicolor* (L.) Moench var *Eusorghum*) extended in developed countries due to its resistance to drought (Kebede et al 2001; Hao et al 2014; Aleminew 2015; Mahama et al 2016), but also because of the species capacity to utilize less fertile lands (Almodares et al 2008; Borghia et al 2013; Szydełko-Rabska 2014). The interaction between plants and environmental factors, poor soils, hydric stress and fertilization management have a significant influence on sorghum yield, limiting it (Showemimo 2007), and this influence was also researched in Romanian conditions (Antohe 2007; Oprea et al 2015, 2016, 2017; Pochişcanu et al 2015).

The main products obtained from grain sorghum and used as food in developed countries are gluten-free beer, breakfast cereals, and bakery products (O'Hara et al 2013; Norwood 2015). Due to the high starch content of sorghum grains (70%) and the

species tolerance to arid conditions, sorghum can be a valuable resource for ethanol production in the biofuels industry (Wylie 2008; Almodares & Hadi 2009; O'Hara et al 2013; Fall et al 2016). Starch is the main component of the endosperm and it ranges between 65 and 90%, the protein content varies between 7 and 15% (Dicko et al 2006), and Antohe et al (2002) highlight the composition similarities of sorghum and maize grains (*Zea mays* L.).

Sorghum is a species with a high yield capacity that depends, in addition to the availability of soil nutrients, on their distribution in the plant vegetative organs, which influences both yield's quantity and quality (Han et al 2011). Nitrogen (N) is the most important macronutrient in terms of yield influence (Hao et al 2014; Saber-Rezaii et al 2009). Nitrogen deficiency reduces the biomass yield of the sorghum crop, by decreasing the leaf surface area and the chlorophyll content (Zhao et al 2005).

Different authors aimed to identify the content of macronutrients in sorghum plants to define the nutritional value and importance of the species. These research focused on sweet sorghum hybrids (*Sorghum bicolor* var. *Saccharatum*) or fodder sorghum hybrids (*Sorghum bicolor* var. *Sudanense*), and the macronutrients (NPK) content fluctuated depending on the research area and the applied technology, as follows: grains nitrogen (N) between 29 and 238 mg dry weight^{-1} (Worland et al 2017); panicle nitrogen (N) from 34.0 to 77.1 mg pot^{-1} and panicle phosphorus (P) between 3.95 and 11.84 mg pot^{-1} (Al-Chammaa et al 2019); leaves nitrogen (N) between 11.8-13.1 g kg dry matter^{-1} (d.m.), leaves phosphorus (P) from 1.5 to 2.1 g kg d.m.$^{-1}$ and leaves potassium (K) 7.3-7.6 g kg d.m.$^{-1}$; stem epidermis nitrogen (N) from 7.0 to 9.5 g kg d.m.$^{-1}$, stem epidermis phosphorus (P) between 1.2 and 1.5 g kg d.m.$^{-1}$ and stem epidermis potassium (K) from 12.1 to 13.5 g kg d.m.$^{-1}$ (Sowinski & Lizka-Brandau 2019); root nitrogen (N) from 2.7 to 54.1 mg pot^{-1} and phosphorus (P) between 3.02 and 7.50 mg pot^{-1} (Al-Chammaa et al 2019).

The present research aimed to identify and comparatively analyze the content in macronutrients of different components of the plant in an assortment of grain sorghum hybrids (*S. bicolor* var. *Eusorghum*) grown in soil and climatic conditions of A.R.D.S. Secuieni (northeast Romania).

Material and Method. The research was conducted in 2019 in the experimental field of A.R.D.S Secuieni – Neamț County, Romania, a unit located in the central part of the Moldavian Plateau (26° 5' east longitude and 46° 5' north latitude), at an altitude of 205.7 m above sea level. The soil type was cambic-chernozem, characterized by a humus content between 2.3 and 3.1%, a slightly acidic soil reaction (pH), and a poor supply of nitrogen (N), a moderate to good supply of phosphorus (P) and a good supply of potassium (K) (Trotuș et al 2015).

The research focused on identifying the macronutrients (NPK) content of the vegetative organs and grains of an assortment of grain sorghum hybrids (*S. bicolor* var. *Eusorghum*). The sorghum hybrids used for this research were: Alimentar, Kalatur, Elan, Armorik, Albanus, Arsky, Foehn, Shamal.

The crop technology included the classic growing techniques for this species, thus the basic soil tillage consisted of an autumn plowing, fertilization was carried out using the complex NP in a dose of 40 kg ha^{-1}, and the sowing density was 300,000 germinating seeds ha^{-1} at a distance between rows of 70 cm. The precursor crop was sunflower (*Helianthus annuus* L.).

Analysis conducted to determine the NPK content were performed by sulfuric acid mineralization followed by titration for total nitrogen (Nt), by mineralization with mineral acids ($HClO_4$, HNO_3) followed by a colorimetric determination for phosphorus (P), and by mineralization with mineral acids ($HClO_4$, HNO_3) followed by flame atomic emission spectrometry determination for potassium (K) content (ICPA 1980). The analysis was carried out only on sorghum main plants, without tillers.

Statistical analysis. Statistical analysis was performed using analysis of variance (ANOVA), followed by Tukey's range test (honestly significant difference), for multiple comparison between all pairs of averages (Ceapoiu 1968).

Results and Discussion

Sorghum hybrids' yield (g plant^{-1}). Alimentar hybrid with the highest value of 98.6 g d.m. plant^{-1} obtained statistically significant differences compared to Foehn (55.0 g d.m. plant^{-1}) and statistically insignificant differences compared to the rest of the hybrids (Table 1).

In terms of stem biomass (Table 1), Alimentar (37.4 g d.m. plant^{-1}) had the highest value and differed significantly from the other seven hybrids. Foehn obtained the lowest stem biomass (19.4 g d.m. plant^{-1}).

In terms of leaves biomass, Alimentar (28.7 g d.m. plant^{-1}) obtained the highest value, and did not register statistically significant differences compared to Elan, but differed significantly compared to the other hybrids. Elan (24.3 g d.m. plant^{-1}) differed significantly from Foehn (16.0 g d.m. plant^{-1}), Arsky, and Armorik (15.7 g d.m. plant^{-1}) but did not have statistically ensured differences from the others (Table 1).

Table 1

Sorghum plants yield (g plant^{-1}), comparison among different hybrids

Hybrid[*]	*Grains*	*Above-ground dry matter (secondary biomass)*			
		Stem	*Leaves*	*Panicle*[**]	*Total*[***]
Alimentar	98.6^{a}	37.4^{a}	28.7^{a}	16.6^{a}	82.6^{a}
Kalatur	78.0^{ab}	26.8^{b}	19.3^{bc}	10.8^{ab}	56.9^{bc}
Elan	89.5^{ab}	23.8^{b}	24.3^{ab}	16.9^{a}	65.0^{ab}
Armorik	67.7^{ab}	22.3^{b}	15.7^{c}	10.0^{b}	48.0^{bc}
Albanus	74.3^{ab}	22.8^{b}	19.0^{bc}	10.9^{ab}	52.7^{bc}
Arsky	70.6^{ab}	23.0^{b}	15.7^{c}	9.7^{b}	48.4^{bc}
Foehn	55.0^{b}	19.4^{b}	16.0^{c}	8.7^{b}	44.1^{c}
Shamal	76.7^{ab}	23.6^{b}	16.7^{bc}	9.5^{b}	49.7^{bc}

[*]Means within columns not followed by the same letter are significantly different at the P<0.05 level.
[**]without grains; [***]sum of dry matter of stems, leaves and panicle.

Analyzing the influence of the grain sorghum hybrids on the panicle biomass, according to data of Table 1, Elan (16.9 g d.m. plant^{-1}) and Alimentar (16.6 g d.m. plant^{-1}) registered significant differences compared to the hybrids Armorik (10.0 g d.m. plant^{-1}), Arsky (9.7 g d.m. plant^{-1}), Shamal (9.5 g d.m. plant^{-1}), and Foehn (8.7 g d.m. plant^{-1}).

Regarding the influence of hybrid on total secondary biomass of the main stem (Table 1), Alimentar obtained the highest value of 82.6 g d.m. plant^{-1}, registering an insignificant difference compared to Elan, but compared to other hybrids, differences were statistically significant. At the same time, Kalatur (56.9 g d.m. plant^{-1}) was significantly different from Foehn (44.1 g d.m. plant^{-1}).

Macronutrients content (% NPK) in sorghum plants. In terms of NPK concentration (%), the highest values were registered for grains and panicles (Table 2). According to Pal et al (1982), macronutrient accumulation increases in grains and panicles, and it decreases for other vegetative organs once plants develop and reach maturity.

Analyzing the nitrogen (N) concentration in grain and vegetative organs grain sorghum plants (Table 2), we noticed differences obtained under the influence of the hybrid, most being statistically assured.

Regarding the nitrogen concentration in grains, Kalatur (1.66%) registers a higher content than the other seven hybrids, obtaining a statistically significant difference compared to Foehn (1.41%) and Shamal (1.29%). Compared to Kalatur, the grain nitrogen content of Elan, Alimentar, Armorik, Albanus, and Arsky did not showed significant differences.

In terms of panicles nitrogen concentration, data of Table 2 show that Foehn (0.60%) obtained the highest value, and Arsky (0.45%) had the lowest concentration, but differences between hybrids were not statistically significant (p>0.05).

Under the influence of the hybrid, the nitrogen concentration in the stem varied between 0.28% for Armorik and 0.49% for Kalatur. The difference between these two hybrids was statistically ensured, with a significant value ($p<0.05$).

Concerning the nitrogen concentration in sorghum leaves, the data of Table 2 show that Alimentar obtained the best value (1.19%), but without registering statistically ensured differences compared to Armorik (1.17%), Kalatur (1.16%), Elan (1.10%), Foehn (1.05%) and Arsky (0.96%). Compared to the nitrogen content in the leaves of Albanus and Shamal hybrids, Alimentar obtained statistically significant differences.

The analysis of phosphorus (P) concentration of sorghum plants shows that this varied under the influence of the hybrid, but in most cases, the differences were not statistically evidenced (Table 2). Under hybrid's influence, the phosphorus content in grains, stem, and leaves did not differ statistically among hybrids.

Concerning the phosphorus concentration in the panicle, Alimentar (0.13%) obtained a higher value than the rest of the hybrids, with statistically ensured differences compared to Elan and Foehn (0.08%), Armorik (0.07%), Albanus and Kalatur (0.06%), Arsky and Shamal (0.05%). Kumar et al (2017) obtained similar results with the following content of macronutrients in sorghum grains: nitrogen (N) between 0.87 and 1.1%, phosphorus (P) from 0.42 to 0.71%, and potassium (K) between 1.93 and 2.79%.

Table 2

NPK content of sorghum grains and above-ground vegetative organs, comparison among different hybrids

Hybrid[*]	*Nitrogen content (%N)*				*Phosphorus content (%P)*				*Potassium content (%K)*			
	Grains	*Panicle*[**]	*Stem*	*Leaves*	*Grains*	*Panicle*[**]	*Stem*	*Leaves*	*Grains*	*Panicle*[**]	*Stem*	*Leaves*
Alimentar	1.55^{ab}	0.55^{a}	0.45^{ab}	1.19^{a}	0.33^{a}	0.13^{a}	0.04^{a}	0.14^{a}	0.61^{a}	1.07^{b}	5.43^{ab}	1.75^{a}
Kalatur	1.66^{a}	0.55^{a}	0.49^{a}	1.16^{ab}	0.27^{a}	0.06^{b}	0.03^{a}	0.11^{a}	0.47^{a}	1.10^{ab}	4.08^{cd}	2.11^{a}
Elan	1.56^{ab}	0.58^{a}	0.42^{ab}	1.1^{ab}	0.32^{a}	0.08^{b}	0.05^{a}	0.13^{a}	0.56^{a}	1.38^{a}	6.07^{a}	2.22^{a}
Armorik	1.54^{ab}	0.57^{a}	0.28^{b}	1.17^{ab}	0.31^{a}	0.07^{b}	0.04^{a}	0.11^{a}	0.61^{a}	1.26^{ab}	5.03^{abc}	1.65^{a}
Albanus	1.5^{abc}	0.53^{a}	0.31^{ab}	0.96^{bc}	0.29^{a}	0.06^{b}	0.03^{a}	0.12^{a}	0.46^{a}	1.36^{a}	6.08^{a}	2.15^{a}
Arsky	1.49^{abc}	0.45^{a}	0.45^{ab}	1.03^{abc}	0.26^{a}	0.05^{b}	0.04^{a}	0.10^{a}	0.56^{a}	1.28^{ab}	3.58^{d}	1.90^{a}
Foehn	1.41^{bc}	0.60^{a}	0.38^{ab}	1.05^{abc}	0.27^{a}	0.08^{b}	0.03^{a}	0.10^{a}	0.46^{a}	1.33^{ab}	4.53^{bcd}	1.73^{a}
Shamal	1.29^{c}	0.49^{a}	0.31^{ab}	0.86^{c}	0.26^{a}	0.05^{b}	0.03^{a}	0.09^{a}	0.57^{a}	1.13^{ab}	4.98^{abc}	1.67^{a}

[*]Means within columns not followed by the same letter are significantly different at the $P<0.05$ level; [**]without grains.

Concerning potassium (K), it is noted that for all sorghum hybrids, the highest values, analyzed both as concentration (%) and amount (g plant^{-1}), were accumulated in stem (Table 2, Figure 3). Pal et al (1982) highlight similar results, explained by the fact that potassium (K) accumulates faster from the early stages of plant growth, as opposed to the slow accumulation of nitrogen and phosphorus (NP).

By analyzing the potassium concentration of sorghum grains, it was highlighted that there were no significant differences registered among hybrids, the values being between 0.61% for Alimentar and Armorik and 0.46% for Foehn.

The potassium concentration in the panicle varied between 1.38% for Elan and 1.07% for Alimentar, and the difference between the two was significant (Table 2).

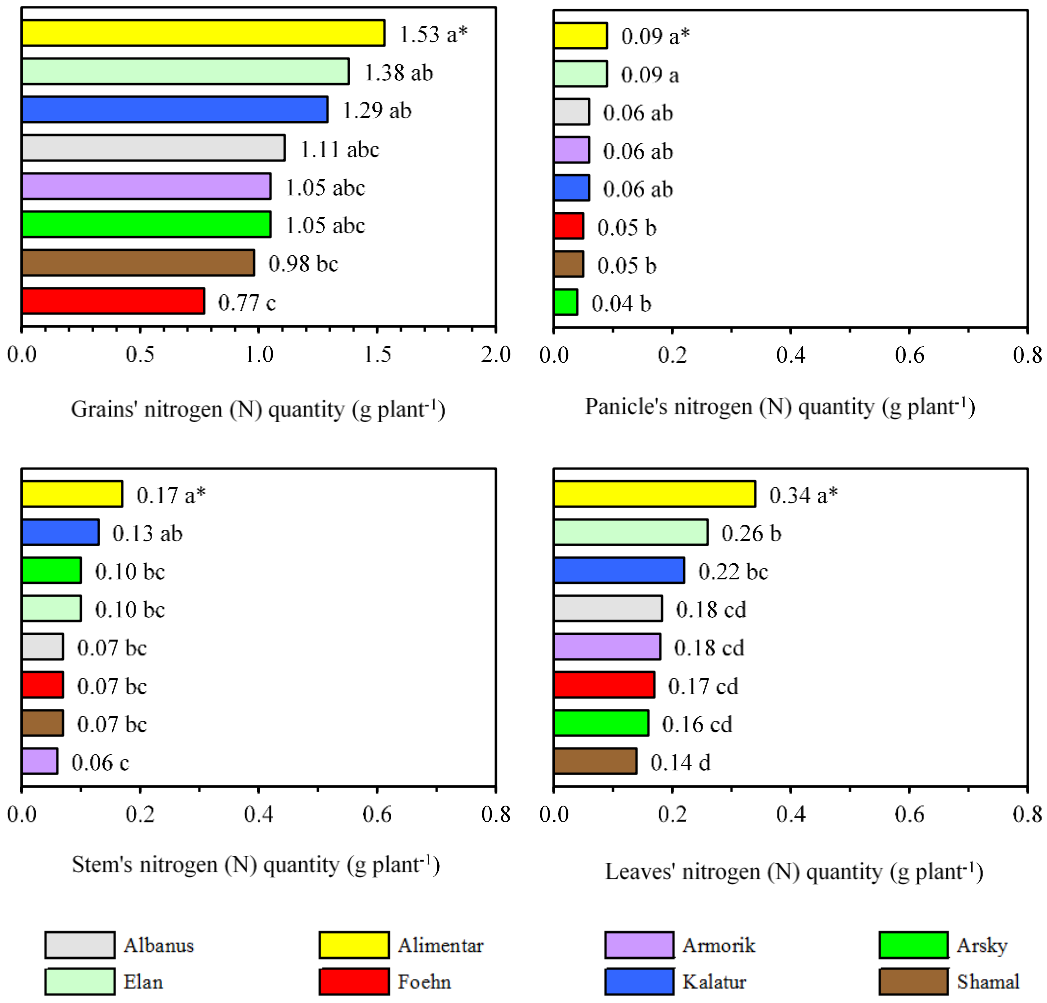
By analyzing the potassium concentration of grain sorghum stems, it was observed that there were no significant differences between Albanus (6.08%), Elan (6.07%), Alimentar (5.43%), Armorik (5.03%), and Shamal (4.98%), but Albanus (6.08%) and Elan (6.07%) had significant differences compared to Foehn (4.53%), Kalatur (4.08%) and Arsky (3.58%).

Concerning the influence of the grain sorghum hybrid on the potassium concentration in leaves, it was observed that the differences were not statistically significant, the highest value being obtained 2.22% by Elan, and the lowest 1.65 % by Armorik.

Macronutrients (NPK) quantity in sorghum plants (g plant^{-1}). Concerning the influence of sorghum hybrids on the amount of nitrogen in grains, data in Figure 1a shows that Alimentar had the highest value (1.53 g plant^{-1}) and was significantly

different compared to Shamal and Foehn, which obtained the lowest values, namely 0.98 g plant^{-1} and 0.77 g plant^{-1}. Elan and Kalatur registered significant differences compared to Foehn.

In terms of hybrid's influence on the quantity of nitrogen in the panicle (Figure 1b), Alimentar and Elan had the highest values (0.09 g plant^{-1}) being significantly different from Foehn, Shamal (0.05 g plant^{-1}) and Arsky. The latest obtained the lowest amount (0.04 g plant^{-1}), but insignificantly different from Albanus, Armorik, and Kalatur that had quantities of 0.06 g plant^{-1}.



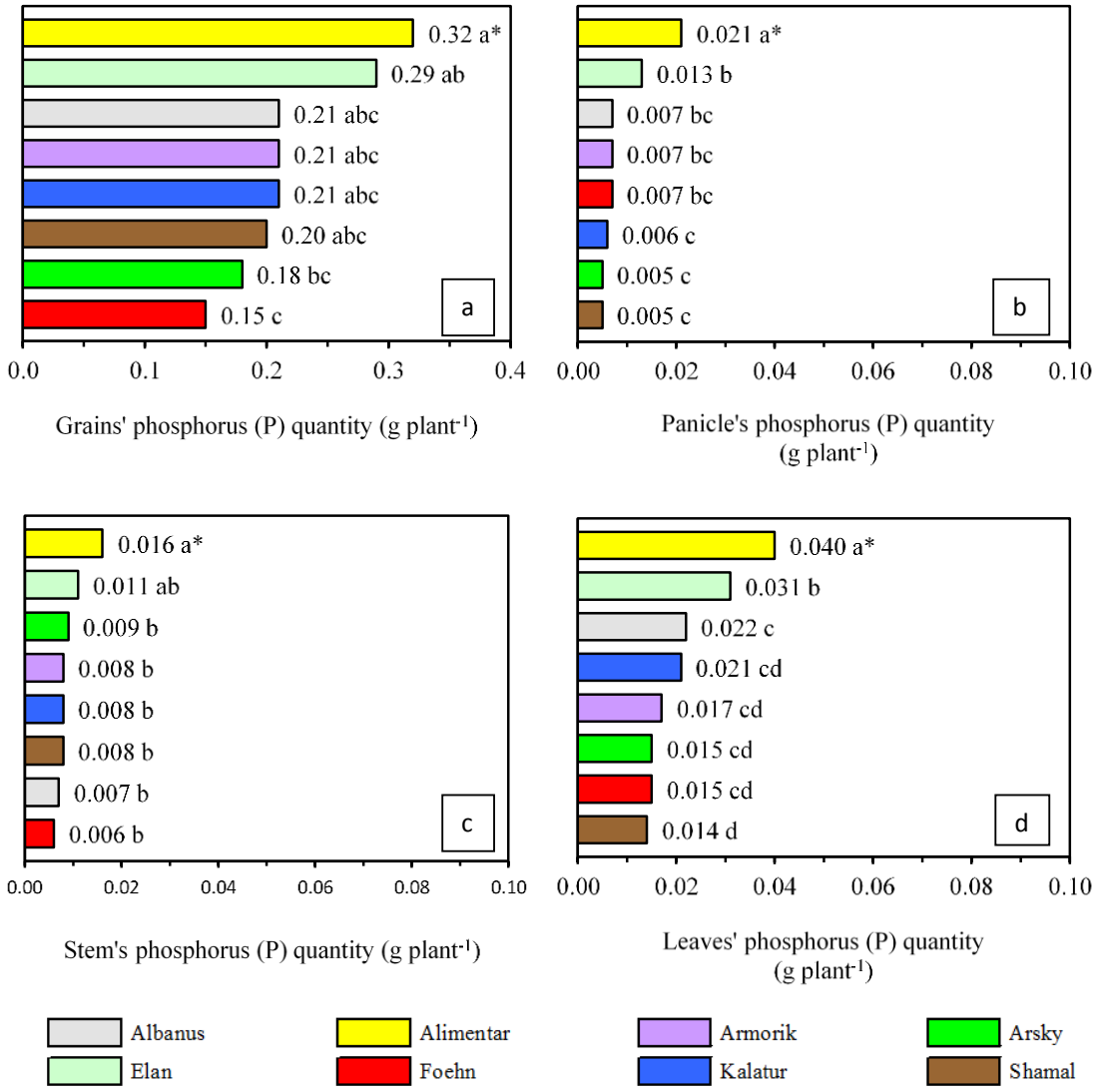
*Means within columns not followed by the same letter are significantly different at the P<0.05 level

Figure 1. Nitrogen quantity (g plant^{-1}) of sorghum grains and above-ground vegetative organs, comparison among different hybrids.

Concerning the influence of hybrid on the quantity of nitrogen in the stem, according to data in Figure 1c, Alimentar had the highest value (0.17 g plant^{-1}). This hybrid did not obtained statistically significant differences compared to Kalatur (0.13 g plant^{-1}), but compared to other hybrids, the differences were significant.

Analyzing the quantity of nitrogen in the leaves (Figure 1d), it was observed that the influence of the hybrid produced significant differences ensured from a statistical point of view. Alimentar (0.34 g plant^{-1}) had a significant difference compared to the other hybrids. At the same time, Elan (0.26 g plant^{-1}) obtained an insignificant difference compared to Kalatur (0.22 g plant^{-1}), but differences were statistically ensured when compared to the other hybrids. Also, the quantity of nitrogen in Albanus leaves (0.22 g plant^{-1}) was significantly different from Shamal (0.14 g plant^{-1}).

Concerning the influence of the sorghum hybrid on the amount of phosphorus in grains, data in Figure 2a. highlight the superiority of Alimentar with a value of 0.32 g plant^{-1} and significant differences compared to Arsky and Foehn, with values of 0.18 and 0.15 g plant^{-1} respectively. At the same time, Elan (0.29 g plant^{-1}) registered a significant difference compared to Foehn, but compared to other hybrids, the differences were not statistically significant.



*Means within columns not followed by the same letter are significantly different at the P<0.05 level

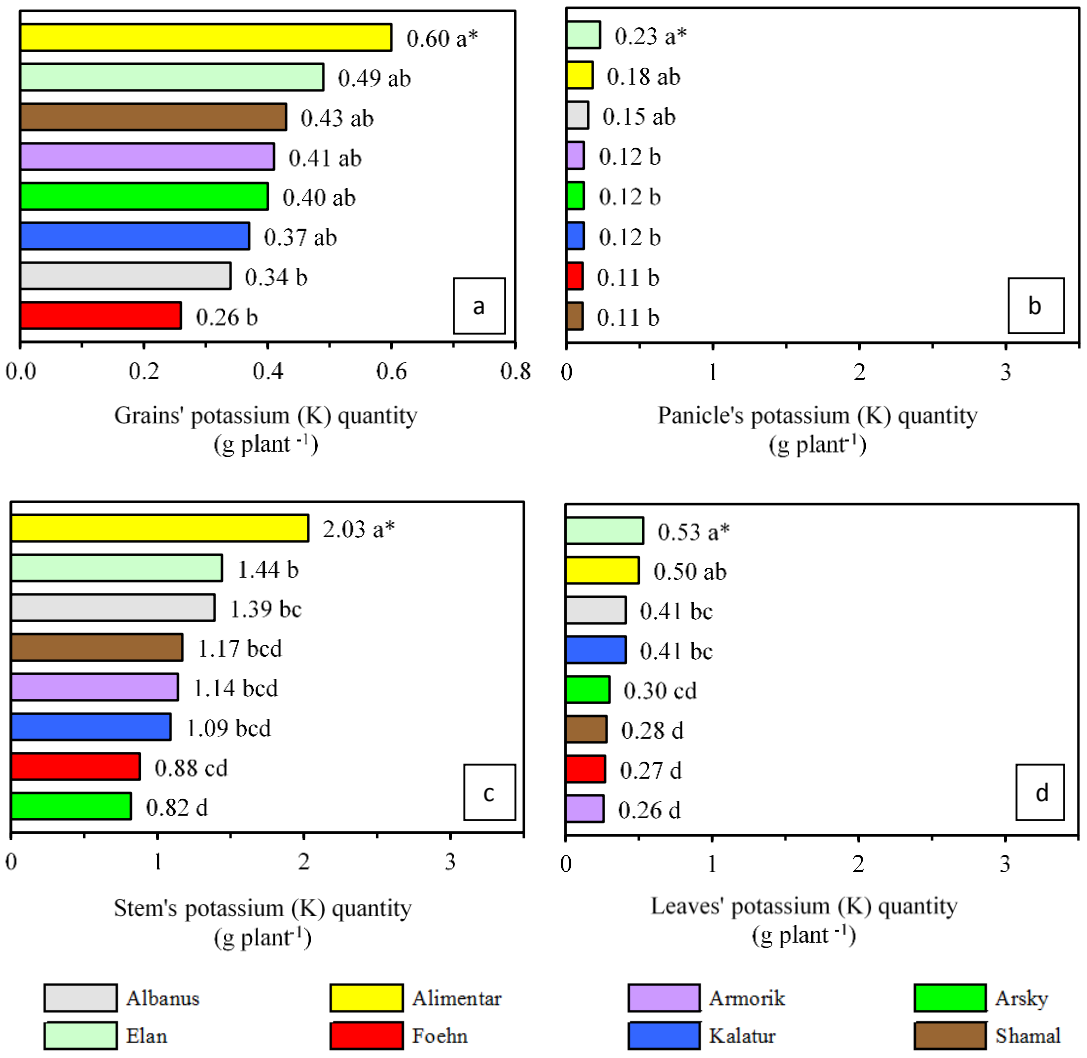
Figure 2. Phosphorus quantity (g plant^{-1}) of sorghum grains and above-ground vegetative organs, comparison among different hybrids.

By analyzing the quantity of phosphorus in the panicle (Figure 2b), it was observed that the influence of the hybrid determined significant differences. Thus, Alimentar with a value of 0.021 g plant^{-1} registered the highest value and significant differences compared to the other hybrids which had values between 0.005 g plant^{-1} (Arsky and Shamal) and 0.013 g plant^{-1} (Elan). At the same time, Elan obtained an amount statistically different from the Kalatur, Arsky, and Shamal.

Concerning the influence of the hybrid on the quantity of phosphorus in the stem data in Figure 2c illustrates that Alimentar (0.016 g plant^{-1}) was significantly different from Arsky (0.009 g plant^{-1}), Armorik (0.008 g plant^{-1}), Kalatur (0.008 g plant^{-1}), Shamal (0.008 g plant^{-1}), Albanus (0.007 g plant^{-1}), and Foehn (0.006 g plant^{-1}). Compared to

Elan, which had a quantity of 0.011 g plant^{-1}, Alimentar generated a difference that was not statistically ensured.

By analyzing the amount of phosphorus in the leaves (Figure 2d), it was observed that Alimentar had a value of 0.040 g plant^{-1} and differed significantly both from Elan which recorded a value of 0.031 g plant^{-1}, and from Albanus, Kalatur, Armorik, Arsky, Foehn, and Shamal. At the same time Elan (0.031 g plant^{-1}) was significantly different from Albanus (0.022 g plant^{-1}), Kalatur (0.021 g plant^{-1}), Armorik (0.017 g plant^{-1}), Arsky (0.015 g plant^{-1}), Foehn (0.015 g plant^{-1}) and Shamal (0.014 g plant^{-1}). At the same time, Albanus (0.022 g plant^{-1}) was significantly different from Shamal (0.014 g plant^{-1}).



*Means within columns not followed by the same letter are significantly different at the P<0.05 level.

Figure 3. Potassium quantity (g plant^{-1}) of sorghum grains and above-ground vegetative organs, comparison among different hybrids.

Analyzing the influence of sorghum hybrid on the amount of potassium in grains (Figure 3a), it was observed that Alimentar recorded the highest value (0.60 g plant^{-1}), which was significantly different from Albanus (0.34 g plant^{-1}) and Foehn (0.26 g plant^{-1}). Compared to the other hybrids, Alimentar generated insignificant differences.

Concerning the influence of hybrid on the quantity of potassium in the panicle (Figure 3b), Elan obtained the highest value (0.23 g plant^{-1}) and a significant difference compared to Armorik, Arsky, Kalatur (0.12 g plant^{-1}), Foehn and Shamal (0.11 g plant^{-1}).

The amount of K in Elan's panicles was not significantly different from Alimentar and Albanus.

Analyzing the quantity of potassium in the stem (Figure 3c), it was noticed that Alimentar had the highest value of 2.03 g plant^{-1}, thus being significantly different from the rest of the hybrids. At the same time, Elan recorded an amount of 1.44 g plant^{-1}, with a significant difference compared to Foehn (0.88 g plant^{-1}) and Arsky (0.82 g plant^{-1}), and compared to Albanus, which had a value of 1.39 g plant^{-1}, and was significantly different from Arsky (0.82 g plant^{-1}).

Concerning the amount of potassium in the leaves (Figure 3d), Elan obtained the highest value (0.53 g plant^{-1}), but insignificant compared to Alimentar (0.50 g plant^{-1}) and significant to the other hybrids. At the same time, Alimentar (0.50 g plant^{-1}) obtained statistically ensured differences compared to Arsky, Shamal, Foehn, and Armorik. Albanus and Kalatur (0.41 g plant^{-1}) had statistically assured differences from Shamal, Foehn and Armorik.

Conclusions. The results of the research concerning the content and the distribution of macronutrients in grain sorghum plants highlighted the influence of the hybrid both on plants' yield, and on macronutrients' concentration and quantity.

Concerning the influence of the hybrid on grains and secondary biomass yield, Alimentar obtained the highest values with 98.6 g plant^{-1} grains and 82.6 g plant^{-1} secondary dry biomass.

Alimentar also obtained the highest nitrogen concentration in leaves (1.19%), the highest phosphorus concentration in grains (0.33%), panicle (0.13%) and leaves (0.14%) and the highest potassium concentration in grains (0.61%).

Although Kalatur obtained the highest nitrogen concentration in grains (1.66%) and stem (0.49%), Alimentar followed closely (grains – 1.55%, stem – 0.45%), without significant differences between the two hybrids. Elan had the highest potassium concentration in the panicle (1.38%) and leaves (2.22%), followed by Alimentar (panicle - 0.61%, leaves - 1.75%) without significant differences.

The NP amount in the secondary biomass of sorghum plants had the highest value for the Alimentar hybrid as for K quantity, Alimentar and Elan obtained similar values without statistically ensured differences between the two.

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