EXPLORING POTASSIUM AND SODIUM COMPOSITION IN HUNGARIAN SORGHUM GRAINS AS KEY MARKERS OF CEREAL GRAIN QUALITY

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Research article

Abstract

Potassium and sodium minerals are essential indicators for assessing the quality of sorghum grains. Therefore, the reported level in all sorghum products must be evaluated, which could provide valuable information on the potential texture and flavour of the final sorghum products.
The study looked at the contents of dry matter (D.M), total protein, potassium (K) and sodium (Na) minerals in Hungarian sorghum (S. bicolor) grains to evaluate the detected ratio on the whole grain and dehulled grain products, which can contribute to the nutritional quality of the measured sorghum grains, that were collected from three distinct sorghum production sites in Hungary. The coupled Plasma Optical Emission Spectroscopy (ICP-OES) method was employed to determine K mg/kg^{-1} and Na mg/kg^{-1} in the sorghum varieties. Statistical analysis showed significant ($P < 0.05$) variations attributed to variety and region groups.
The results showed that the amount of potassium in the Hungarian sorghum varieties was higher than the previous levels reported in the literature. The average potassium levels in the Kacarg, Nyíregyháza, and Szeged regions were 3939.7 mg/kg$^{-1,}$ 3679.7 mg/kg^{-1}, and 4344.6 mg/kg^{-1}, respectively. The highest average of Na mg/kg^{-1} of (189.8 mg/kg-1) was recorded by the Alföldi 1 variety sourced from Szeged; the recorded value was revealed in the grain bran attributed to the dehulling process. Despite a high level of Na mg/kg-1 in the Alföldi 1 variety from the Szeged site, the ratio of K: Na was 27:1. Furthermore, the study showed that the protein levels of whole grains, endosperm (grits) and bran ranged from 16.2%, 17.0%, and 15.4%, respectively.
The findings provided valuable insight into updated information on the investigated nutrients in Hungarian sorghum varieties, which can benefit breeders and producers concerned about sorghum sector advancements, contributing to Hungarian sorghum's nutritional value and potential applications in the food and sorghum product industries.

Keywords: sorghum grains, dehulling, potassium, sodium, region

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INTRODUCTION

The productivity of sorghum in western regions is contingent upon its capacity to flourish in hot, arid circumstances and its resistance to infestation, which maintains production and sustainability (Khalifa & Eltahir, 2023). Sorghum is a highly adaptable crop among the top five cereal crops worldwide. It is also a vital food source, fodder, feed, and fuel (Kakabouki et al., 2021).

Several approaches are followed in sorghum production in Hungary; it involves nutrient management through various breeding enhancements (Nagy et al., 2023). Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) is a common, accurate procedure utilized for element content detection for various food raw materials, which can give nutrients a good insight into foodstuff composition (Khan et al., 2014). Crops have advanced mechanisms to control the equilibrium of potassium and sodium ions, crucial for maintaining cellular balance, supporting metabolic functions, and improving resilience to diverse harsh environments. This has resulted in high-grain quality (Mazzaferro et al., 2021; Kubar, 2018). However, potassium and sodium minerals have interdependent functions in facilitating the proper functioning of one another. Sodium may serve as an osmotic co-factor when there is inadequate potassium availability, given certain circumstances (Thorne & Maathuis, 2022; Keisham et al., 2018). Dry matter (DM) is a useful metric for assessing the quality of cereal grains. It affects the concentration of minerals in processed grains and can improve the digestibility of the final products (Puntigam et al., 2021). In addition, the scientific research showed that the High-quality sorghum genotypes were distinguished by a diverse range of protein contents, ranging from 6% to 18% (Adebo & Kesa, 2023; Espinosa-Ramírez & Serna-Saldívar, 2016). The quantities of potassium and sodium significantly influence the texture and quality of cereal grain products. Accordingly, potassium chloride has similar benefits to sodium chloride in the production of dough and bread (Chen et al., 2018).

Whole grains inherently possess a naturally low amount of sodium, which may differ across various consumed grains (Henney et al., 2010). Survey data from previous reports shows fluctuations in the potassium content of processed cereals, including cereals made from bran and refined flour (Food Safety Authority of Ireland, 2022). Maintaining a balanced ratio of potassium and sodium is crucial for optimizing cereal foods' quality and nutritional value (Food Safety Authority of Ireland, 2022). Excessive sodium levels may lead to health issues, including high blood pressure and heart disease (Winiarska-Mieczan et al., 2016). Potassium plays a vital role in the regulation of blood pressure and the facilitation of several physiological processes (Stone et al., 2016). Consuming cereal products could boost daily potassium intake. According to the standards set by the World Health Organization (WHO), individuals should aim to consume a daily amount of potassium ranging from 3,500 to 4,700 mg (90 mmol). Additionally, it is recommended to limit sodium intake to less than 2,000 mg (86 mmol) per person per day (Drewnowski et al., 2015),

The study aimed to analyse the levels of potassium (K) and sodium (Na) minerals in white sorghum (Farmsugro 180) and red sorghum (Alfoldi 1) cultivated in three distinct sorghum sites in Hungary: Kacarg, Nyíregyháza, and Szeged. The investigation can substantially contribute to evaluating the quality of whole and husked grains from the respective varieties.

MATERIAL AND METHODS

1.2. MATERIALS

We obtained identical samples of three sorghum racial variants from three locations in Hungary: Kacarg (loam clay), Nyíregyháza (sandy), and Szeged (Luvisol). The samples were dehydrated. The grain samples were ground using the Retsch SK-3 hammer mill with a 1 mm screen. A meticulous grinding procedure was applied to the whole-grain samples. The experiment's findings were compared between the whole grains (ground) and the husked grains (husker).

2.2. HUSKING PROCEDURE

The research used the (TM05C husker), Satake Engineering Co.'s apparatus to dehull sorghum grain, which produced two distinct fractions: bran and endosperm (grits).

2.3. DETERMINATION OF THE CRUDE PROTEIN

As described in the reference (ISO 20483:2013, 2013), the Kjeldahl technique was used to measure the nitrogen levels in the sorghum samples. Moreover, a block heater was set at 420–430 °C for 2 h after the cooling step, followed by the digestion step. Furthermore, we used the Converter 6.25 to determine the crude protein content.

1.4. DETERMINATION OF DRY MATTER

The procedure was applied by following measurements reported by (Hellevang, 1995), started by placing the samples in an oven adjusted to a temperature range of 130–135 °C. The specimen was desiccated in the oven until it attained a uniform weight. Determining the mass of the desiccated specimen: The dehydrated sample was carefully removed from the oven. The weight of the dried sample was recorded, and dry matter content of the sample was determined using the following formula:

$$\text{Dry Matter Content (\%)} = \frac{\text{Weight of Dried Sample}}{\text{Weight of Original Sample}} \times 100$$

2.5. DETECTION OF MINERAL CONTENTS

The grain samples were examined with the applying accuracy procedure: We employed, BCR CRM 189 (whole grain), as accreditation of measurements (John & Taylor, 2023). The measurements were conducted in many phases (Kovács et al., 1996). We used the iCAP 7400 apparatus from Thermo Scientific, which utilizes inductively coupled plasma optical emission spectroscopy (ICP-OES) technology. The chemical reagents required for conducting element assays at certain wavelengths, namely K 404.721 nm and Na 330.237 nm, were acquired from VWR International Ltd. (Geldenaaksebaan, Belgium). We quantified 1 g The materials underwent a process of aqueous acid digestion, which included both predigesting and digestion phases. The specimens were exposed to a temperature of 60°C for 30 minutes using a model block (MIM OE-718/A) for the digestion process after adding 10 ml of nitric acid (HNO3, 69% v/v). After cooling, 3 cm3 of hydrogen peroxide (H2O2, 30% v/v) was added to the samples, which were then transferred to the first digestion phase. We elevated the temperature of the digestor to 120°C. We placed it for 90 minutes before deactivating it and allowing it to stabilise for of 10 to 20 minutes. add volume of 50 cm3 using ultra-pure water originated from (Millipore SAS Co, Ltd, France). And was followed by filtration process using filter paper (MN 640W) to strain the homogenized solution. The element contents were determined and expressed as mg/kg^{-1}.

2.7. STATISTICAL ANALYSIS

The SPSS 28.0 statistical analysis program was utilized to differences detection. The performed data sets were followed normality property, and followed by An ANOVA one-way analysis was used to find out variability in dry matter and total protein. In addition, a distinct model was used to assess variance in mineral content group, using a significance value of $P \leq 0.05$.

RESULTS AND DISCUSSION

The findings were indicated the difference of K mg/kg^{-1} and Na mg/kg^{-1} among the investigated varieties ($P<0.05$), result aligned with previous study by (Osman et al., 2022). while, the variability of the mineral contents, dry matter and total protein attributed to site source (Desta et al., 2023). Showed a significance value $P < 0.05$, as was interpreted in Table 1.

3.1. DRY MATTER

As was mentioned above, dry matter content can affect the mineral concentration of cereal grains (Puntigam et al., 2021). No mentionable variation was detected, according to endosperm (grits) and bran, as they showed averages of 861 g/kg^{-1} and 890 g/kg^{-1}, respectively. Even though the dry matter percentage varied slightly, the average of the whole grains, which was 889%, showed that the dry matter content had re-concentrated on the husked grains ($P < 0.05$), as shown in Table 1. The revealed level of dry matter in the tested grain varieties was higher than the reported level by (Osman et al., 2022), where the reported level ranged from 720 to 775 g/kg dry matter (DM).

3.2. TOTAL PROTEIN

The protein concentration in sorghum grains varied substantially depending on whether the grain was whole or processed, and processes such as dehulling could alter it (Table 1). The Farmsugro180 variety had the highest average protein content, ranging from 10.0 g/kg^{-1} (bran) to 17.5 g/kg^{-1} (endosperm), which differed from whole grains; in contrast, the Alfoldi 1 variety from Nyíregyháza and Kacarg had the lowest protein, ranging from 17.5 g/kg^{-1} ($P > 0.05$), as shown in Table 1. The finding was similar to a previous study (Adebo & Kesa, 2023); the study emphasized the total protein content variation based on whole and dehulled grains. Another study showed that the analysis of protein derived from the whole and decorticated sorghum genotypes to determine their functionality and characterisation (Espinosa-Ramírez & Serna-Saldívar, 2016). In their study, (János et al., 2016). found that the protein content in Hungarian sorghum hybrids varied between 10.25% and 14.25%. Certain

Table 1. Descriptive analysis of nutrient content on diverse sorghum varieties

Variables	Grain parts	D.M g/kg^{-1}	Protein g/kg^{-1}	K mg/kg^{-1}	Na mg/kg-^{1}
	whole grain	890±0.2	15.3±1.0	4590.5±1759.1	34.3±1.5
Alföldi 1(K)	Endosperm	882±1.2	12.0±0.8	1666.4±373.5	53.1±3.0
	Bran	837±0.1	10.0±0.1	3854.8±151.9	67.7±2.7
	whole grain	852±1.6	16.4±0.9	4931.0±1106.4	44.2±17.0
Alföldi 1(Ny)	Endosperm	903±2.1	16.5±0.1	3620.1±179.7	62.6±22.1
	Bran	907±2.1	16.8±1.2	2869.4±280.5	76.0±19.3
	whole grain	890±3.4	12.5±0.1	5129.7±742.1	26.8±0.89
Alföldi 1(Sz)	Endosperm	843±5.5	11.3±0.3	3840.8±809.1	166.2±10.9
	Bran	834±0.1	15.6±3.0	4924.4±362.9	189.8±6.8
	whole grain	886±3.0	16.3±0.5	4723.8±85.5	37.5±12.7
Farmsugro 180 (K)	Endosperm	853±0.1	17.0±0.2	2125.5±118.3	69.8±23.2
	Bran	840±0.1	16.4±0.2	4024.6±193.7	67.0±2.0
	whole grain	919±2.7	17.0±0.5	3875.5±163.9	37.5±12.7
Farmsugro 180 (Ny)	Endosperm	974±1.2	17.4±0.1	1689.2±193.9	32.8±9.9
	Bran	874±0.9	17.5±1.2	4490.0±1055.0	66.7±23.3
	whole grain	897±1.2	12.0±1.0	5324.1±44.1	33.4±0.01
Farmsugro 180 (Sz)	Endosperm	890±2.0	16.2±0.2	4022.8±2027.3	163.2±52.0
	Bran	878±2.0	1.7±0.2	3746.9±1292.0	130.8±9.2
Whole grains	-	0.25	0.41	0.01	0.50
Processed grains	-	0.05	0.53	0.02	<.001

*Value of the potassium and sodium were analyzed based on three replications, while the dry matter (D.M) and protein were analyzed based on two replications (m/m)%, labels after the variety refer to source sites: K: Kacarg, N: Nyíregyháza, Sz: Szeged.

hybrids exhibited protein content values of 10.59% and 14.25%, lower than the current reported values of whole and dehulled grains.

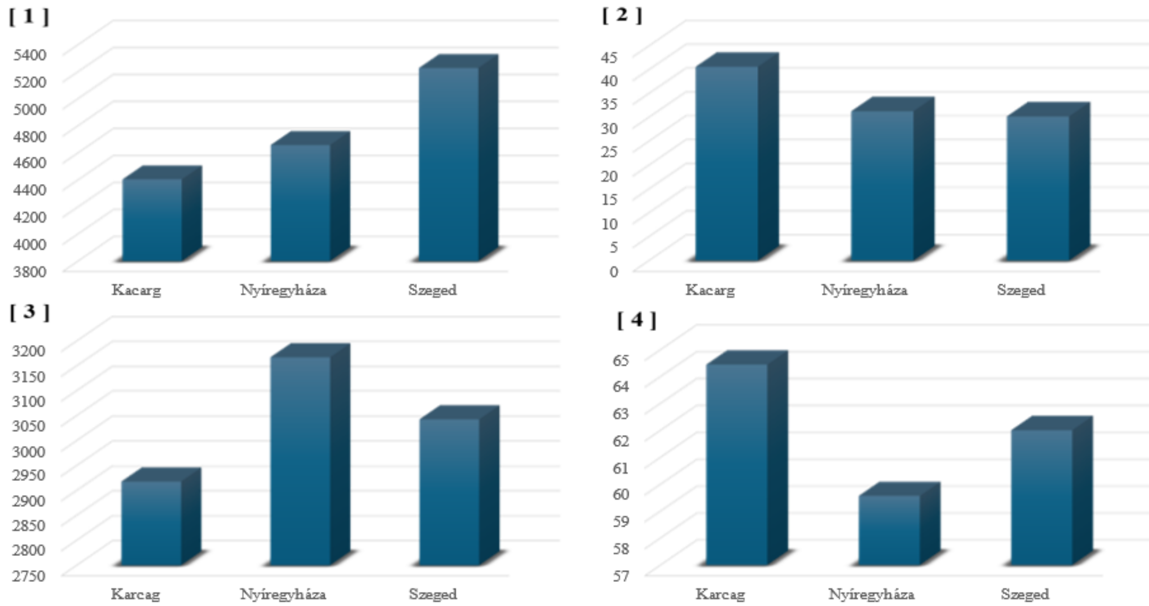
3.3. POTASSIUM AND SODIUM

The findings showed that the amounts of potassium and sodium minerals in whole sorghum grains and dehulled samples differed depending on the varieties of grains tested (Table 1; P > 0.05). This discovery is significant and supports prior research done by (Adebo & Kesa, 2023). Furthermore, both mineral contents were influenced by three source regions, as displayed in Figure 1(1-4). When the Nyíregyháza site showed a significant variation in K mg/kg and Na mg/kg contents attributed to whole grains and dehulled grains, the result was linked (Rubio-Armendáriz 2023; Ramírez & Saldívar, 2016). Potassium and sodium minerals sourced from three distinct regions, Kacarg, Nyíregyháza and Szeged, showed an average of K mg/kg-1 and Na mg/kg-1 within 3939.7 mg/kg-1, 3679.7 mg/kg, 4344.6 mg/kg, 67.3 mg/kg, 71.3 mg/kg, and 160.3 mg/kg, respectively.

Table 1. Ratios of K: Na contents on diverse examined sorghum varieties

Variety	Ratio (K: Na)
Farmsugro 180 (K)	60: 1
Farmsugro 180 (Ny)	67: 3
Farmsugro 180 (Sz)	28: 1
Alföldi 1(K)	56: 9
Alföldi 1(Ny)	26: 1
Alföldi 1(Sz)	37: 2

*Demonstrated values based on P≤0.05



*Numbers refers to [1] K mg/kg-1content based on regions (whole grains), [2] Na mg/kg-1content based on regions (whole grains), [3] K mg/kg-1content based on regions (dehulled grains), [4] Na mg/kg^{-1}content based on regions (dehulled grains)

Figure 1. Average of K mg/kg^{-1} and Na mg/kg^{-1}contents based on diverse regions, $P \leq 0.05$

The results indicated that the Szeged site had the highest K mg/kg and Na mg/kg content within the ratio of 27:1, which can provide an acceptable recommended level according to (National Academies of Sciences, Engineering, 2019). To ensure the appropriate K: Na ratio, the ratios of diverse varieties were calculated and recorded as shown in Table 2. Previous literature provides information on the mineral composition of Hungarian sorghum grains, specifically, the concentrations of potassium and sodium found in these grains, which range from 3490 to 5000 mg/kg and 113.7 mg/kg, respectively, according to (Ildikó & , Andrea 2022).

CONCLUSION

The experiment attempted to evaluate the potassium and sodium mineral concentrations of two prevalent sorghum varieties grown at three sorghum cultivation sites in Hungary. The assessment necessitates the crucial role of potassium and sodium levels, which can estimate the quality degree of whole and husked grain and predict the potential quality of the end product derived from the examined varieties. The report has discussed the

The limitations of the presented results cannot serve as a comprehensive marker for assessing grain quality. However, they may provide valuable insights to breeders on the variance between the same variety and the influence of the production site on the nutritional properties. The research demonstrated that the amounts of potassium and sodium could vary depending on their origin. Major nutrient contents, such as dry matter, crude protein, K, and Na, may significantly impact the end product's texture, flavour, and shelf life. Hence, the ratio measurements of the tested minerals contribute to meeting the desired needs of various dietary groups. For instance, cereal grains with high potassium (K) and sodium (Na) content may not fit those suffering from hypernatremia and high blood pressure. Therefore, the current investigation has drawn attention to two critical ingredients in cereal grains that can be controlled from the farm soil to the individual tables, facilitating public health goal achievements.

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REFERENCES

Adebo, J. A., & Kesa, H. (2023). Evaluation of nutritional and functional properties of anatomical parts of two sorghum (Sorghum bicolor) varieties. *Heliyon*, *9*(6), e17296. https://doi.org/10.1016/j.heliyon.2023.e17296

Chen, G., Hu, R., & Li, Y. (2018). Potassium chloride affects gluten microstructures and dough characteristics similarly as sodium chloride. *Journal of Cereal Science*, *82*, 155–163. https://doi.org/10.1016/j.jcs.2018.06.008

Desta, K. T., Choi, Y. M., Shin, M. J., Yoon, H., Wang, X., Lee, Y., Yi, J., Jeon, Y. ah, & Lee, S. (2023). Comprehensive evaluation of nutritional components, bioactive metabolites, and antioxidant activities in diverse sorghum (Sorghum bicolor (L.) Moench) landraces. *Food Research International*, *173*(P2), 113390. https://doi.org/10.1016/j.foodres.2023.113390

Drewnowski, A., Rehm, C. D., Maillot, M., Mendoza, A., & Monsivais, P. (2015). The feasibility of meeting the WHO guidelines for sodium and potassium: A cross-national comparison study. *BMJ Open*, *5*(3), 1–6. https://doi.org/10.1136/bmjopen-2014-006625

Espinosa-Ramírez, J., & Serna-Saldívar, S. O. (2016). Functionality and characterization of kafirin-rich protein extracts from different whole and decorticated sorghum genotypes. *Journal of Cereal Science*, *70*, 57–65. https://doi.org/10.1016/j.jcs.2016.05.023

Food Safety Authority of Ireland. (2022). *Monitoring Sodium and Potassium in Processed Foods September 2003 to December 2021* (Issue September 2003). www.fsai.ie

Hellevang, K. J. (1995). Grain Moisture Content Effects and Management. In *NDSU Extension Service* (pp. 1–8). http://www.ag.ndsu.edu/extension-aben/documents/ae905.pdf

Henney, J. E., Taylor, C. L., & Boon, C. S. (2010). Strategies to reduce sodium intake in the United States. In *Strategies to Reduce Sodium Intake in the United States*. https://doi.org/10.17226/12818

Ildikó Kolozsvári , Ágnes Kun, M. J., & , Andrea Palágyi, C. B. and C. G. (2022). Agronomic Performance of Grain Sorghum (Sorghum bicolor. *Agronomy*, *12*, 1185. https://doi.org/10.3390/ agronomy12051185

János, J., Lydia, E., Károly, A., József, Z., Lajos, B., & János, T. (2016). PROTEIN CONTENT ENHANCEMENT IN GRAIN SORGHUM (Sorghum bicolor (L.) Moench) BY CONVENTIONAL PLANTBREEDING METHODS. *Fascicula Protecţia Mediului*, *XXVII*, 39–46. https://www.cabdirect.org/cabdirect/FullTextPDF/2017/20173122016.pdf

John R.N. Taylor, J. T. (2023). *ICC Handbook of 21st Century Cereal Science and Technology* (pp. 161–171). https://doi.org/doi.org/10.1016/B978-0-323-95295-8.00039-3

Kakabouki, I., Tataridas, A., Mavroeidis, A., Kousta, A., Roussis, I., Katsenios, N., Efthimiadou, A., & Papastylianou, P. (2021). Introduction of alternative crops in the Mediterranean to satisfy EU Green Deal goals. A review. *Agronomy for Sustainable Development*, *41*(6), 1–19. https://doi.org/10.1007/s13593-021-00725-9

Keisham, M., Mukherjee, S., & Bhatla, S. C. (2018). Mechanisms of sodium transport in plants—Progresses and challenges. *International Journal of Molecular Sciences*, *19*(3). https://doi.org/10.3390/ijms19030647

Khalifa, M., & Eltahir, E. A. B. (2023). Assessment of global sorghum production, tolerance, and climate risk. *Frontiers in Sustainable Food Systems*, *7*(June), 1–20. https://doi.org/10.3389/fsufs.2023.1184373

Khan, N., Choi, J. Y., Nho, E. Y., Habte, G., Jamila, N., Hong, J. H., Ryu, K. Y., Park, K. S., & Kim PhD., K. S. (2014). Determination of Macronutrients in Spices by Inductively Coupled Plasma-Optical Emission Spectrometry. *Analytical Letters*, *47*(14), 2394–2405. https://doi.org/10.1080/00032719.2014.908384

Kovács, B., Gyôri, Z., & Prokisch, J. (1996). Communications in Soil Science and Plant Analysis A study of plant sample preparation and inductively coupled plasma emission spectrometry parameters. *Communications in Soil Science and Plant Analysis*, *October 2014*, 37–41. https://doi.org/10.1080/00103629609369625

Kubar, G. M. (2018). Effect of potassium (K+) on growth, yield components and macronutrient accumulation in Wheat crop. *Pure and Applied Biology*, *7*(4). https://doi.org/10.19045/bspab.2018.700183

Nagy, R., Murányi, E., Bíróné Molnár, P., Szepesi, J., Győri, Z., Veres, S., Remenyik, J., & Sipos, P. (2023). Assessment of Bioactive Profile of Sorghum Brans under the Effect of Growing Conditions and Nitrogen Fertilization. *Agriculture (Switzerland)*, *13*(4). https://doi.org/10.3390/agriculture13040760

National Academies of Sciences, Engineering, and M. (2019). Dietary Reference Intakes for Sodium and Potassium. In *Dietary Reference Intakes for Sodium and Potassium*. https://doi.org/10.17226/25353

Osman, A., Abd El-Wahab, A., Ahmed, M. F. E., Buschmann, M., Visscher, C., Hartung, C. B., & Lingens, J. B. (2022). Nutrient Composition and In Vitro Fermentation Characteristics of Sorghum Depending on Variety and Year of Cultivation in Northern Italy. *Foods*, *11*(20). https://doi.org/10.3390/foods11203255

Puntigam, R., Slama, J., Brugger, D., Leitner, K., Schedle, K., Wetscherek-Seipelt, G., & Wetscherek, W. (2021). Fermentation of whole grain sorghum (Sorghum bicolor (l.) moench) with different dry matter concentrations: Effect on the apparent total tract digestibility of energy, crude nutrients and minerals in growing pigs. *Animals*, *11*(5). https://doi.org/10.3390/ani11051199

Stone, M. S., Martyn, L., & Weaver, C. M. (2016). Potassium intake, bioavailability, hypertension, and glucose control. *Nutrients*, *8*(7), 1–13. https://doi.org/10.3390/nu8070444

Winiarska-Mieczan, A., Kwiecień, M., Kwiatkowska, K., & Krusiński, R. (2016). Breakfast cereal as a source of sodium, potassium, calcium and magnesium for school-age children. *Journal of Elementology*, *21*(2), 571–584. https://doi.org/10.5601/jelem.2015.20.1.763