

Thesis of doctoral (PhD) dissertation

**EVALUATION OF THE MINERAL CONTENTS OF ALTERNATIVE
CEREAL GRAIN FOR NUTRITIONAL PURPOSES**

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1. Introduction and objectives

Cereals are the bedrock of global agriculture, nourishing people worldwide and embodying agricultural biodiversity. In the 1960s, attention shifted to the origins of crop domestication in different regions. The importance of sustainable food systems is increasingly evident as we face daunting global challenges such as fluctuating weather patterns, changing dietary patterns, population growth, and climate change exacerbation. Meeting these imperatives will require effective strategies, regulations, and innovative approaches.

Our research supports the crucial necessity and tackles exciting scientific questions. We are investigating the nutritional profiles of different cereal varieties under different soil conditions attributed to different region collections and shedding light on their nutritional performance. This aspect of our research is of significant importance, as it provides valuable insights into the nutritional value of these cereals. Focusing on the alternative cereal grains involved *S. bicolor* and *P. miliaceum*, alongside counterparts to staple cereal grains such as winter wheat and oats, specifically, the experiment was conducted and looked to understand the diverse crop's response to nitrogen fertilizer supplementation and its reflection on optimizing the nutritional compositions such as crude protein (N), P, S, Zn, K, Ca, Na, Mg, Fe, Cu, and Mn. We investigate how these cereals respond to N fertilizer through meticulous field experiments and accumulate nutrients driven by their distinct attributes of diverse varieties.

Our research findings underscore the immense potential of the examined *S. bicolor* and *P. miliaceum* varieties. These varieties, tailored to meet diverse culinary demands, are promising and reassuring for the agricultural sector. Their proven adaptation to various environmental conditions makes them a reliable choice for the current agricultural sector transformation, offering resilience in changing climate patterns.

Our study evaluated the significant impact of a novel dehulling process on nutritional density, particularly focusing on the husked milling fractions. By examining and comparing whole and dehulled grains, we addressed the nutritional properties viability. We sorted the resulting milling fractions from the Husking Fraction Time Unit (HFTU) process attributed to the 30s-, 50s-, and 80s-time units per (second). The innovative husking approach, a key aspect of our research hypothesis, played a crucial role in our study.

The novel husking process outcomes significantly affect scientific research and the agricultural and food industries. It has the potential to revolutionize the production of diverse fortified grain products under N fertilizer conditions while the dehulling process enhances the estimated characteristics of the final products. The findings demonstrated a marked improvement in the

nutritional properties of the investigated raw material of the alternative cereal grains that could meet the dietary group requirements and customer preferences, sparking optimism for the industry's future and adoption of alternative cereal grains in the region.

In addition, the relevant findings indicated that the HFTU process significantly contributed to genetic trait improvements when it was achieved by applying the new dehulling method to 51 samples of *S. bicolor* and Kafir races in the breed line; the study provided a valuable opportunity to enhance the genetic traits of the sorghum grain inbred line, which can contribute to sorghum breeding programs. Furthermore, the respective investigation outcomes showed that the HFTU approach altered the nutritional contents and proved that the genotypes resist dehulling.

While it is widely recognized that *S. bicolor* and *P. miliaceum* are key alternative cereal crops that can significantly enhance global food security, our research underscores the critical need for more comprehensive studies. These studies are necessary to comprehend the factors influencing the respective cereal grains' nutritional properties, such as the measured grain varieties' functional properties and enzymatic activities. Due to concerns with digestion, taste, and flavor preference, the two alternative cereal grains examined in this research must be promoted to introduce them to European cuisine. This necessitated the main study objective to enhance their acceptability by exploring their adaptation under specific soil conditions to contribute sustainable food resources and innovate new processing techniques that can imply antinutritional reduction, optimizing nutrient properties that meet human dietary needs and lifestyles in developed countries.

From forgotten historical treasures to contemporary crossbreeds, these assortments not only encourage but also supply farmers, researchers, and consumers with new insight into the cereal diet. They offer a promising future for cereal products for human consumption, with the crops being an alternative cereal food source.

1.2.Objectives of factors affecting mineral compositions under N fertilizer conditions

1. To explore the possibility of *S. bicolor* and *P. miliaceum* as alternative cereal grains in the region and assess their influence by the soil-type conditions that can affect the elemental profile characteristics, focusing on the mineral nutrients such as (crude

protein (N), P, S, K, Ca, Fe, Mg, Na, Cu, Zn, and Mn) among the cereal grain varieties cultivated under N fertilizer conditions.

2. To systematically investigate the raw materials (whole grain flour from different grain sources) based on their mineral compositions, which are implied from different grain varieties under different soil conditions. The investigation was supported by promoted measurements for sorghum crops based on the two soil types, Karcag (loam clay) and Nyíregyháza (sandy), among common regions for sorghum cultivation in Hungary.

1.3. Objectives of the novel husking technique

1. To optimize the nutritional properties of *S. bicolor* and *P. miliaceum* for human consumption through exploring a new sufficient husking process, namely Husking Fraction Time Unit (HFTU) to maintain and enhance the essential nutritional composition of the substitute cereal grains involving (total protein (N), total dietary fiber, ash, P, S, Ca, K, Mg, Fe, Mn, Na, Cu, and Zn) based on the implications of the employed time units per (second).
2. To improve the nutritional value of different dehulled sorghum grain varieties by examining the differences in nutrient redistribution and re-concentration across cereal grain varieties that resulted from the 30s and 80s, considering varied nutritional traits to each variety and region.
3. An analysis of the nutritional disparities of milling fractions (bran and endosperm/grits) and whole grain (flour) and evaluating their appropriateness for different dietary requirements may elucidate significant variances in their nutritional characteristics.
4. To contribute and address *S. bicolor* and *P. miliaceum* as sustainable food resources that can adapt and thrive in different soil types. When integrated into meals, they improve and provide a healthy diet; all these properties can be intelligent solutions for food security and SDGs.
5. To draw attention to the superior varieties of Hungarian sorghum, which have adapted to various treatments, such as cultivation under N fertilizer conditions and applying the HFTU technique. Comparing the varieties has presented unique nutritional characteristics, sparking intrigue to be utilized as alternative benchmark varieties.
6. To Update data on examined Hungarian *S. bicolor* and *P. miliaceum* grain varieties and interpret the revealing results of their nutritional profiles compared to international literature outcomes.

1.4. Objectives of the precision and sufficiency of the husking technique

1. To comprehend the impact of removing the HFTU process on the nutritional composition of sorghum in male sterility inbred lines from two distinct sorghum races such as (*S. bicolor* and *S. kafir*) and how the innovative technique can influence the nutritional properties based on various maturity stages.
2. To assess the effectiveness of the HFTU technology on the colour stability characteristics of the two sorghum races inbred male sterility line. Contributing by providing valuable knowledge to enhance the recognition of processed sorghum's nutritional characteristics and colour profiles and paving the way for the respective sorghum race enhancement programs.

2. Material and Methods

The study involved categorizing various cereal grain collections based on soil types. The research followed an experimental design, collecting 250 sorghum grain varieties. These varieties included 20 samples of winter wheat, 20 samples of oats, 250 samples of *S. bicolor*, and 100 samples of *P. millet*, cultivated under nitrogen fertilizer conditions in sandy soil. nutritional contents such as crude protein and elemental composition (N, K, P, S Cu, Fe, Na, Mn and Zn), along with thousand kernel weight (TKW) and tannin level measurements, were determined in the first collection, as were displayed in Table 2.

The second collection comprised commercial sorghum grain varieties from different regions in Hungary. Experimental measurements included total dietary fiber, ash, protein, and essential minerals, besides measuring ash, total dietary fiber, and tannin contents. Various varieties from this collection, such as ES Föehn, ES Monsoon, AS1 2021, Alföldi 1, and Farmsugro180, were selected for husking process measurements. On the other hand, we employed the ES Föehn variety as the sorghum benchmark for the nutritional properties of the sorghum grain varieties collections 1 and 2. The details of the respective commercial varieties are presented in Table 4. Lastly, considering the impact of husking process measurements, the third collection involved two sorghum races (*S. bicolor* and Kafir) on male sterility inbred lines.

The research design was carefully selected and balanced to encompass common regions for sorghum production in Hungary. Therefore, the comparative approach offered a comprehensive evaluation of *S. bicolor* grain nutritional quality compared to staple cereal grains at the first stage of the project's conduct. It also explores sorghum as an alternative cereal grain for human consumption in non-native production sites, addressing emerging solutions in agricultural development sectors.

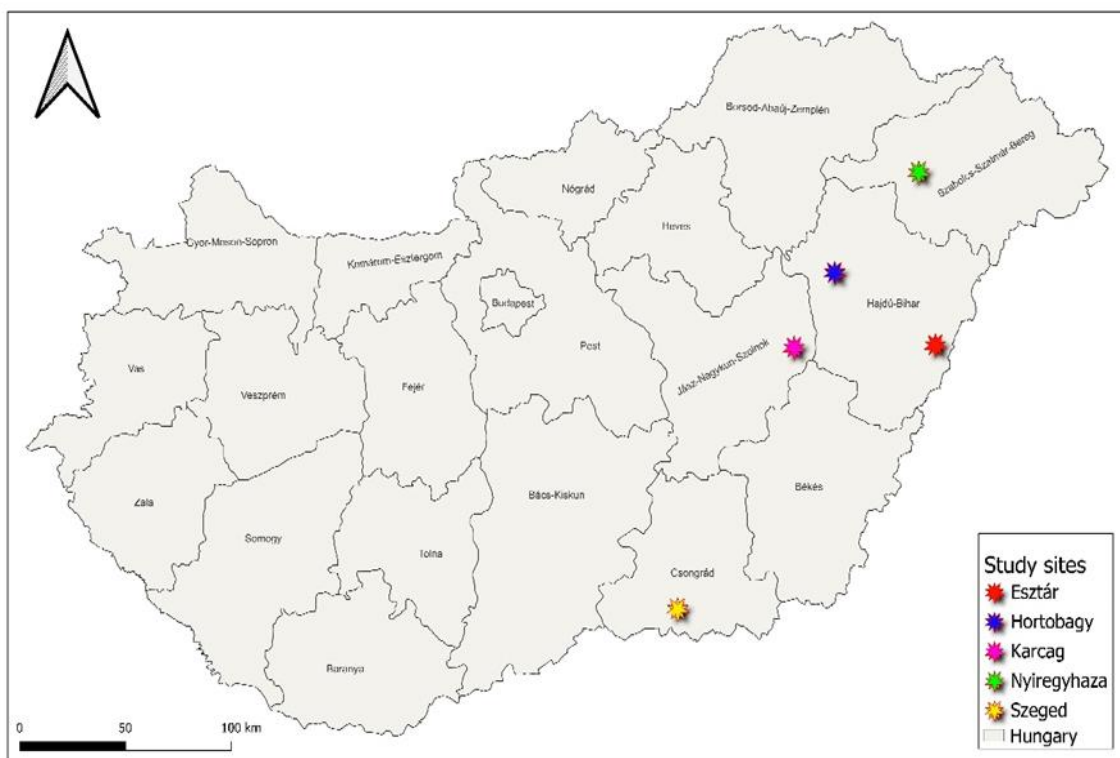


Figure 1. The distinct collections of sorghum grain varieties in Hungary

2.1. Reagents and equipment

2.1.1. Raw protein reagents

VWR International Ltd, Radnor, Pennsylvania, USA, supplied the distillation system. The sulphuric acid (with a concentration of 18 mol/l and a density of 1.84 g/ml at 20 °C), the boric acid (in aqueous solution, with a density of 40 g/l at 20 °C), and the catalyst ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) were purchased from different laboratory shops in Hungary. The specific characteristics of these items varied depending on the source of supply.

2.1.2. Elemental content reagents

The iCAPTM 7400 system, an ICP-OES analyzer, was purchased from PerkinElmer Inc. of Waltham, Massachusetts, USA, catalog number 84230074181.

Ultrapure water was purchased from Millipore, S.A.S., France, and chemical reagents from VWR International Ltd, Geldenaaksebaan, Belgium.

We accredited the elemental investigation procedure by utilizing the whole grain, specifically, (BCR CRM 189) as standard International Plant Exchange Network, according to (John & Taylor, 2023)

2.1.3. The husker equipment

Satake Engineering Co. (Hiroshima, Japan) developed the TM05C husker tool. Industrias Machina Zaccaria Limeira Rua, address Laranjal, 180, created the S A—51466324000150 rice mill. Bairro: Vila Fascina. CEP: 13484–016.

2.1.4. Application of the dehulling process

In the pre-stages of the study investigation, we utilized The Zaccaria PAZ-1/DTA rice mill (Figure 2) has a 100-gram capacity for paddy rice samples. It has a four-pole motor that generates 0.5 horsepower (0.37 kW). The rice is whitened by a friction principle involving a rubber brake and an abrasive ring. Slotted and recessed cylinders partition the rice into varying sizes and thicknesses. A digital control console regulates and supervises the mill, enabling the standardization of test results. The mill is intended to be a compact, all-in-one unit that can be operated in 60 seconds.

We employed the cereal grain husker machine, the TM05C model, manufactured by Satake Engineering Co. in Hiroshima, Japan. This particular grain testing mill offers adjustable time units, as noted by (Wang, 2005).

In our procedure, we weighed 50 grams of sorghum grains and loaded them into the TM05C husker (Figure 2), equipped with an abrasive wheel (46–60 mesh) and 0.54 kW power capacity. The abrasive wheel rotated at a speed between 800 and 1,100 rpm and was screened through a No. 60 mesh sieve (4760 μm). Our investigation revealed that grain sizes ranging from 3.0 mm to 4.5 mm were efficient, with 4.0 mm to 4.5 mm diameters being the most effective (Figure 7). The respective kernel sizes were selected for further investigation of the HFTU process.



Figure 2. The utilized huskers (1) Zaccaria No. 1. testing rice mill for 60 (S), Institute of Research, Karcag. (2) Satake husker for the husking technique, Lab of Food Science and Technology

2.4.4. Spectro colorimeter digital camera

Konica Minolta, Chroma Metre (CR-410, 2002), originated from Minolta Co. Ltd. (Japan), as shown in Figure 3.



Figure 3. Measurement of the colour profile of the respective grain varieties by utilization of CR-410 Konica Minolta Camera

2.5. Investigation of diverse cereal grain under N fertilizer controlling

2.5.1. Soil chemical properties

The first collection of the study comprised five distinct *S. bicolor* varieties, namely ES Föehn, Alföldi 1, ES Albanus, Albita, and Farmsugro180, along with diverse cereal grains, namely winter wheat (SE15), oats (Lota), and *P. miliaceum* (Biserka, Rumenka, and Gyöngyszem). The diverse cereal grains were cultivated under sandy soil conditions, while the sorghum crop was promoted to two experiments under two soil types: sandy soil and loam clay soil. as detailed in Table 2. Furthermore, it referenced different pH ranges of 7.3 - 7.5 and 4.7 - 4.9.

Table 1. Soil chemical Properties of the 2020 and 2021 cultivation seasons

Regions	Loam clay	Sandy
pH (KCl 1:2.5) [-]	4.8	7.4
Plasticity index [K_A]	41.5	26.5
Carbon content [m/m%]	0.21	<0.1
Organic matter [m/m%]	3.1	0.98
(NO_3+NO_2)N mg/kg	7.2	4.3
AL-(P_2O_5) mg/kg	131.0	124.5
AL-(K_2O) mg/kg	358.5	263.5
Na mg/kg	36.8	34.5
Zn mg/kg	2.3	1.45
Cu mg/kg	2.0	2.1
Mn mg/kg	48.0	37.4

* The abbreviations refer to K_A = soil cohesion number, AL- P_2O_5 = phosphorus-pentoxide (ammonium lactate solution), and AL- K_2O = potassium-oxide (ammonium lactate solution). Data received from the Research Institute of Nyíregyháza and Karcag, University of Debrecen.

3. Results and Discussion

The chapter aimed to present the revealed results of the nutritional properties of the examined cereal grains as sorted in the material and methods chapter, as the first collection of the research project was focused on the dietary properties evaluation of the substitute cereal grains, specifically, *S. bicolor* and *P. millet* in a comparison into two staple cereal grains such as winter wheat and oats were cultivated on the sandy soil under N fertilizer conditions. Accordingly, the measurements were conducted on the whole grains (ground) attributed to diverse varieties samples (Tables 2, 4, and 5); the varieties were involved in essential mineral content measurements such as N, P, S, Ca, K, Mg, Fe, Cu, Na, Mn, and Zn by applying the accredited procedures of cereal grain measurements were detailed earlier.

While the study was undertaken deeply to investigate the nutritional variability of the two potential cereal grain varieties, particularly *S. bicolor* and *P. millet*, and examine their suitability for human consumption, the approach was conducted by employing our novel procedure of the Husking Fraction Time Unit (HFTU) process into respective cereal grains. The study design was performed to evaluate the implication of a novel husking process on the tested nutrient content involving ash, total dietary fiber, total protein, P, S, Ca, K, Mg, Fe, Cu, Na, Zn, and Mn; furthermore, the investigation procedure was promoted to determine the tannin level and colour profile assessments for the selected *S. bicolor* and *P. millet* husked products.

Overall, the third collection of study evaluations was performed to evaluate the efficiency and precision of the novel Husking Fraction Time Unite (HFTU) process by applying the procedure to the two sorghum races inbred lines. This can provide good insight into the grain race inbred line and the implications of the employed husking process on the nutritional profile of *S. bicolor* and Kafirin races inbred line.

Each relevant finding was explained and clarified, highlighting the practical implications and applicability of the study's conclusions.

3.1. Results of the different cereal grain cultivation under N fertilizer conditions

The first collection of our project was designed based on the implementation of N fertilizer impact on the mineral contents instance of N, P, K, S, Ca, Mg, Cu, Fe, Zn, Na, and Mn levels on diverse cereal grains, which were attributed to the sandy soil conditions when the experiment treatment consisted of control (without N fertilizer) and treated (with N fertilizer),

60 kg/ha for *S. bicolor* and 80 kg/ha for winter wheat, oat, and *P. millet* based on the sandy soil, as was shown in (Tables 2 and 4). While the study has promoted the *S. bicolor* and grain varieties by conducting an experiment attributed to soil types based on different cultivation sites Karcag (loam clay) and Nyíregyháza (sandy) by utilizing N fertilizer, it consisted of a treatment of 60 kg/ha and 120 kg/ha. Accordingly, the findings outcomes differences were assessed based on $P \leq 0.05$.

Table 2. Statistical analysis of experiment variables of macro-mineral in the diverse cereal grain attributed to the sandy soil for 2020 and 2021 production seasons

Factor	DF	K	P	S	Mg	Na	Ca
Variety	9	5203965.6***	3172480.8**	2580987.8***	1942966.78***	4751.8***	2204934.2***
Year	1	1507782.3 ^{NS}	1761730.2**	82164.841 ^{NS}	8269.761 ^{NS}	13.57 ^{NS}	37432.6 ^{NS}
Treatment	1	1800662.1 ^{NS}	337315.7***	71922.7 ^{NS}	127349.1***	197.1 ^{NS}	127349.1***
Variety × Treatment	9	3005099 ^{NS}	1388880.8 ^{NS}	476603.40**	271224.0***	1228.9***	1120402.01***
Year × Treatment	1	23162838***	4396736.9 ^{NS}	13741.32 ^{NS}	120402.1***	1650.5***	271224.0***

*Denotes differences that are statistically significant. All results are based on a dry basis of three reading replications, attributed * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$, NS for no significance value

Table 3. Statistical analysis of experiment variables of macro-mineral in the *S. bicolor* grain attributed to the sandy soil and loam clay soil for 2020 and 2021 production seasons

Factor	DF	K	P	S	Mg	Na	Ca
Variety	4	12761506**	216942.7***	231781.64***	302363.64***	3885.26***	231781.64***
Year	1	4400886**	608228.0**	5183332 ^{NS}	1197.49 ^{NS}	458.587 ^{NS}	81916.83***
Treatments	1	6733110.0**	1774920**	47042.8 ^{NS}	429703.37***	1786.588 ^{NS}	2135.7 ^{NS}
Soil type	1	10310975***	1690.6 ^{NS}	3403.07 ^{NS}	303919.09***	303919.09***	3403.07 ^{NS}
Variety × Treatment	4	26620008 ^{NS}	1613011 ^{NS}	43134.9 ^{NS}	165543.9 ^{NS}	1060.301 ^{NS}	1703347**
Year × Treatment	1	1148466 ^{NS}	1217987.9 ^{NS}	189984.14 ^{NS}	178504.41**	7302.7722***	513.298 ^{NS}

*Denotes differences that are statistically significant. All results are based on a dry basis of three reading replications, attributed * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$, NS for no significance value

Table 4. Statistical analysis of experiment variables of microminerals on diverse cereal grains attributed to the sandy soil for 2020 and 2021 production seasons

Factor	DF	Fe	Cu	Zn	Mn
Variety	9	3158.73 ^{***}	11567.86 ^{***}	193.70 ^{***}	8488.3 ^{***}
Year	1	49.077 ^{NS}	0.484 ^{NS}	49.08 ^{***}	193.861 ^{NS}
Treatment	1	1082.8 ^{***}	37.1 ^{**}	60.95 ^{***}	101.9 ^{NS}
Variety*Year	9	1346.5 ^{***}	13.52 ^{***}	549.14 ^{**}	551.75 ^{***}
Variety*Treatment	9	1327.8 ^{***}	25.62 ^{***}	151.49 ^{***}	121.9312 ^{***}

*Denotes differences that are statistically significant. All results are based on a dry basis of three reading replications, attributed * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$, NS for no significance value

The findings indicated that the variety factor significantly impacted the mineral contents in the diverse cereal grains (Table 4), with a significant value of $P < 0.05$ compared to the treatment and year factors.

As well as the consequences of variety factor in the *S. bicolor* crop in the two soil types (Table 5), the result was confirmed by significant differences of $P < 0.05$.

Table 5. Statistical analysis of experiment variables of micromineral on *S. bicolor* grains attributed to the sandy soil and loam clay soil for 2020 and 2021 production seasons

Source of variation	DF	Fe	Cu	Zn	Mn
Variety	4	209.6047 ^{**}	2.24464 ^{NS}	40.3546 ^{NS}	5792899 ^{***}
Year	1	124.19324 ^{**}	0.4123298 ^{NS}	1.920695 ^{NS}	5.290229 ^{**}
Treatments	1	341.8363 ^{***}	1.594015 ^{NS}	107.5333 ^{***}	4.8372142 ^{NS}
Soil type	1	155.81064 ^{**}	5.877845 ^{***}	58.10965 ^{***}	11.506477 ^{**}
Variety× Year	4	84.19092 ^{NS}	1.2145947 ^{NS}	33.19503 ^{NS}	4.049608 ^{**}
Variety × Treatment	4	198.0003 ^{NS}	1.739524 ^{NS}	41.4461 ^{NS}	6.9483814 ^{NS}
Variety × Soil type	4	112.79251 ^{NS}	0.6792296 ^{NS}	84.6806 ^{***}	1.52658 ^{NS}

*Denotes differences that are statistically significant. All results are based on a dry basis of three reading replications, attributed * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$, NS for no significance value

The study was performed according to the current transformation in agricultural breeding and production, which resulted from climate change through a variety of mechanisms, including fluctuations in annual precipitation, average temperatures, heat waves, alterations in microbial populations, pests, or vegetation, and global modifications in atmospheric CO₂ or ozone levels, as well as sea level reduction. Therefore, we selected the comparison approach to evaluate the

variability of the nutritional profile of the common crop in the Mediterranean region, such as winter wheat and oat, compared to potential staple crops, such as *S. bicolor* and *P. millet* grains attributed to soil type conditions.

Nitrogen is essential for optimizing cereal grains' nutrient content and development. The employed comparison approach provided a good insight into the nutritional properties' variability of the staple cereal grains (winter wheat and oat) and potential cereal grains (*S. bicolor* and *P. millet*) cultivated under the N fertilizer controlling, particularly in the sites that crop (sorghum) is not staple. We applied an adequate dose of N fertilizer to each crop to optimize the nutrient contents. Accordingly, that was evidenced by the response to N fertilizer by the diverse cereal grain varieties, accumulation of the various mineral contents in the crop grains, considering the other impacted variables involving Variety, Treatment, Year, Variety x Treatment, and Variety x Year, in addition to Soil type, and soil type x Variety instance of same sorghum variety sourced from two soil types namely Karcag (loam clay) and Nyíregyháza (sandy). The findings of the comprehensive assessment were summarized that the presented factors significantly impacted the elemental profile of the examined cereal grain, including (N, P, K, Ca, S, Fe, Zn, Cu, Na, and Mn), considering the meteorology factors involving the temperature degree and the level of the precipitation during the crop development, in addition to various maturity stages in case of *S. bicolor* crop.

The study findings demonstrated that nitrogen fertilizer significantly impacted the mineral profile of winter wheat, oats, *P. millet*, and *S. bicolor*. Additionally, sorghum grain gained further promoted investigation measurements by conducting experiments on two soil types (sandy and loam clay) under two different nitrogen fertilizer application rates. Overall, the results from these experiments indicated that various factors significantly influenced nutrient management and evaluations for all the examined cereal grains. The prevalent results are interpreted as follows:

- The findings were aligned with (Gao et al., 2022); the author combined the accumulation of phosphorus (P) minerals and their availability in the cultivation site's soil.
- Supported by published findings (Hao et al., 2020), the study explained the reflection of soil acidification after N fertilizer application on the potassium (K) mineral accessibility to cereal grain.
- According to the revealed finding, we linked it to previous findings conducted by (Hemesh, 2020; Przygocka-cyna & Grzebisz, 2017); the scientist returned the sulphur mineral deficiency or reduction to the applied fertilizer and variety type.

- The results indicated that the *S. bicolor* and *P. miliaceum* have an abundant Mg mg/kg level, which was linked to the finding (Singh, 2016), the author linked the nutritional components of various millet grains.
- Improving agricultural practices and understanding the factors that affect and interact with soil mineral content could optimize and enhance the mineral levels in crop grains. The research results demonstrated decreased sodium (Na) and calcium (Ca) levels in the cereal grains analyzed. These factors include chemical processes, such as
- hydrolysis, which was caused by changes in environmental circumstances. However, the findings indicated that the decrease in sodium (Na) and calcium (Ca) levels was associated with higher amounts of hydrogen ions (H⁺) in the soil. The cation exchange mechanism was estimated to have aided the elimination of Na⁺ and Ca²⁺ ions from the soil particles. Consequently, sodium (Na) and calcium (Ca) levels in *S. bicolor* grains decreased in loam clay and sandy soil.
- Specifically, The study results indicate that using N (27% N CAN) fertilizer positively affected the nutritional content of the *S. bicolor* grains. It is estimated that the formation of calcium ion compounds from the fertilizer perhaps reduced the availability of phosphate ions (PO₄³⁻) after the hydrolysis reaction. The *S. bicolor* grains have a good capacity for nutrient absorption, as discussed in a previous report (Barłóg, 2023). The authors investigated many factors that affect the efficiency of fertilizer consumption, including soil type, crop type, and procedures for applying fertilizer. They also emphasized the need for soil testing to enhance the effectiveness of nitrogen management planning.

According to revealed findings of the fluctuated mineral profile characteristics based on the sandy soil conditions instance of the different cereal grains, which were indicated that the comparison approach was sufficient to evaluate *S. bicolor* and *P. miliaceum* as alternative cereal grains based on the levels of N, K, P, S, Fe, Cu, Zn, Na, and Mn in the diverse varieties as were shown in (Tables 1-5), with statistical differences ($P < 0.05$). Through mineral composition analysis, we can identify cereal grain forms with elevated quantities of vital minerals such as iron, zinc, magnesium, and calcium, which could lead to the choice and advancement of these nutrient-rich varieties for cultivation. Biofortified crops have the potential to greatly enhance the consumption of vital minerals in populations that primarily

depend on cereals as their main source of food and nutritious resources. The study results have been reported to include the pertinent outcomes of the respective collections:

Based on data analysis the findings were demonstrated the variations % of the mineral compositions (Table 5), between winter wheat/ sorghum in the (sandy soil), winter wheat/ sorghum in the (clay soil), winter wheat/millet in the (sandy soil) of N (25.8%, 35.6%, 11.3%) g/kg, P (0.4%, 4.6%, 10.1%), K (13.2%, 15.9%, 27.0%), Ca (45.3%, 45.5%, 42.5%), S (12.9%, 18.5%, 1.0%), Mg (19.0%, 25.6%, 22.6%), Fe (12.5%, 4.5%, 25.8%), Cu (34.4%, 41.1%, 9.0%), Zn (10.9%, 1.8%, 29.4%), Na (10.4%, 7.7%, 28.0%), and Mn (19.1%, 19.9%, 32.9%) respectively, the comparison approach was sufficient in evaluating of study precision as was noticed by the low variation percentage of the total protein content in the winter wheat and P. millet within 1.7% followed by low variation percentage of S% and Cu% within 1.0% and 9.0% respectively, which are the most mineral can interact with protein content in crop tissues. The lowest variation ranged between sorghum grain sourced from the sandy and loam clay soil. On the other hand, the variations % of the mineral compositions between oat/ sorghum in the (sandy soil), oat/ sorghum in the (clay soil), oat/millet in the (sandy soil) of N (17.8%, 28.7%, 1.7%), P (6.1%, 10.0%, 15.2), K (3.9%, 27.8%, 10.4%), S (8.0%, 1.8%, 9.1%), Ca (19.3%, 19.6%, 22.6%), Mg (10.1%, 17.5%, 14.1%), Cu (51.9%, 56.8%, 20.0%), Fe (31.5%, 36.3%, 23.4%), Zn (22.5%, 32.0%, 9.0%), Na (15.4%, 17.6%, 44.9%), and Mn (22.2%, 36.3%, 20.7%), respectively.

Similar results revealed the mineral composition variation between winter wheat and oat and *S. bicolor* and *P. miliaceum* grains, which can be a guide to promoting both cereal grains as unique sources of minerals.

The limitation of the respective collection can be addressed by the limited evaluation of the cereal grains based on the soil type, which the experiment of the *S. bicolor*, *P. miliaceum*, winter wheat, and oat was carried out on the soil type (sandy); furthermore, the cultivation was conducted for the two cultivation seasons (2020 and 2021), which is considered a short production term.

We created the principal component analysis (PCA) to assess the relationship between the diverse varieties and mineral composition. We selected the first component, which presented the relationship within 29 %. When the component demonstrated a strong relationship (positive) between all the examined mineral contents and varieties, expect a weak relationship (negative) between ES Föehn, Albita, and farmsugro180 varieties from the sandy soil source and Albita* from the loam clay source.

On the other hand, the relationship analysis of the tested mineral contents (Figure 4) was evidenced by the precision of the study measurements when the component demonstrated a strong relationship between the P, Ca, Fe, Zn, Mg, Cu, Ca, Na, and S. At the same time, the K and a weak correlation with Na mineral content ($P > 0.05$). The revealed finding was aligned with study outcomes (Khalfalla et al., 2024); the report explained the relationship between most minerals that can interact and affect each other and accordingly can impact cereal grain quality.

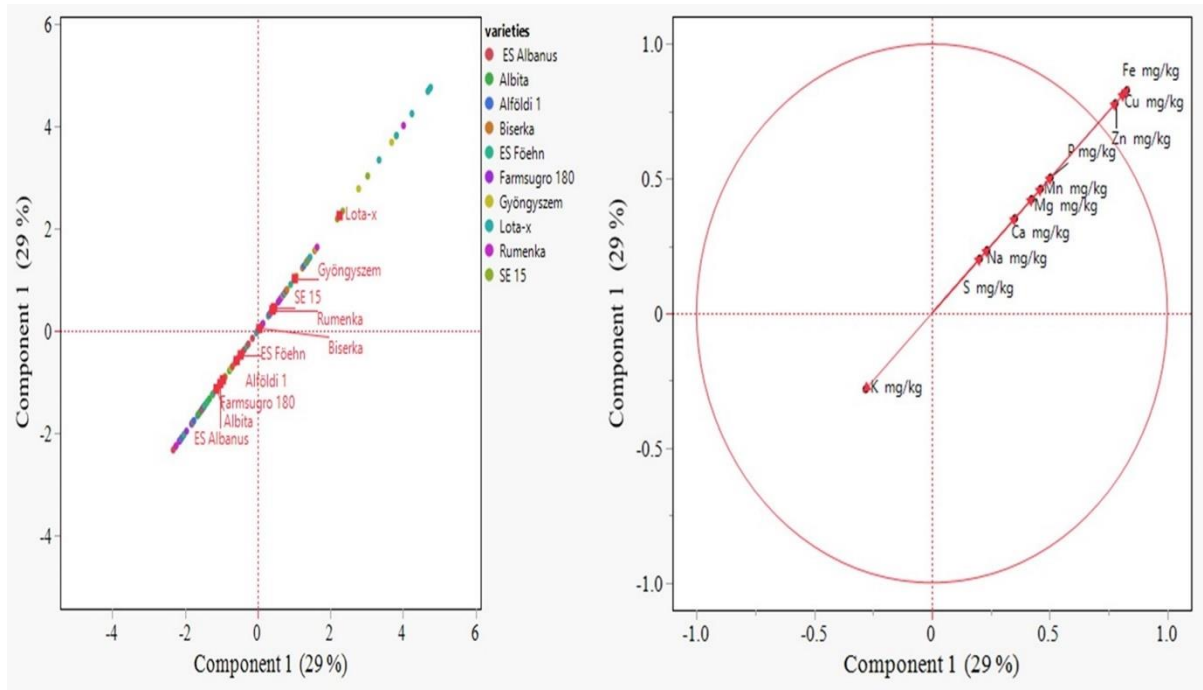


Figure 4. The principal component analysis of diverse cereal grain under N fertilizer sandy soil conditions, $P \leq 0.05$

3.2. Results of the Husking Fraction Time Unit (HFTU) technique

The accuracy of the HFTU was evaluated based on the employed time efficiency, which was 30s and 80s for *S. bicolor* varieties. The set times for the dehulling process of *P. miliaceum* varieties were 30s and 50s. These details can be found in the material and methods section. Additionally, we combined the results of the husking process from Tables 6 to 9 with the variations in nutritional mineral profiles.

We conducted a precision evaluation of the husking process by comparing the percentage of the obtained bran fraction to the waste (g) amounts. The following details explain all relevant results independently.

After dehulling, sorghum and millets are nutritionally optimized, with increased nutrient concentration and decreased others. The innovative procedure can replace conventional grain

processing, eliminating processing-related problems, shortening processing times, and producing an adequate husked percentage. The HFTU technology, with its ability to fit grain processing in developed nations by shortening processing time and meeting nutritional needs, offers a promising future for making *S. bicolor* and *P. miliaceum* healthy for human consumption.

The impact of the dehulling process, as we've discovered through our research outcomes, is a complex interplay of different time units 30s, 50s, and 80s for the *S. bicolor* and *P. miliaceum* dehulling process, which the technique has unique features were highlighted as follows:

The second stage of the investigation was performed to examine the implications of the novel husking (HFTU) process on the nutritional properties such as (ash, total dietary fiber, total protein, P, K, S, Ca, Mg, Fe, Zn, Na, Cu, and Mn) on a dry basis. Their variation was attributed to diverse varieties sourced from different regions.

Advancements in agricultural practices for production and health benefits have resulted in an increase in sorghum utilization in non-native regions due to climate change. Food science research can be facilitated by addressing new challenges to expand *S. bicolor* and *P. miliaceum* production in Europe. Therefore, research and development strategies are necessary to improve the nutritional properties and physical characteristics of *S. bicolor* and *P. miliaceum* -based products. Thus, grain processing should be considered as one of the strategies for enhancing the bioavailability of minerals in processed sorghum grain. Our research identified the pressing necessity for contemporary processing technology to replace conventional methods to improve the quality of *S. bicolor* and *P. miliaceum* edible grains.

As part of our research, we collaborated with the Institute of Research at the University of Debrecen, located in Karcag, to evaluate the rice mill for the 60s using huskers from Zaccaria No. 1. However, the technique proved to be insufficient for dehulling the cereal grains. It did not exhibit a significant variance, as it was originally configured for 60 seconds.

To ensure a dehulling process that is both precise and adequate, we employed the satake husker, which is specifically designed for the husking process of various cereal grains. That was conducted at the Food Science and Technology Laboratory at the University of Debrecen. Consequently, the study was undertaken to address the processing issues that were causing the inadequacy of pathogen removal and the time-consuming nature of the process. The findings indicated statistical variance ($P < 0.05$) among the 30s- and 80s-time units as findings outcomes explained in (Tables 14 to 17) and (Figures 24 (1,2)- 27 (1,2)) in the case of sorghum grain varieties and races. In comparison, the 30s- and 50s-time units were employed for *P. miliaceum* varieties, as shown in Table 17 and Figure 27 (1,2). Which inevitably impacted the quality of

the dehulled fractions due to significantly influencing the redistribution and reconcentrate of nutrient contents of the resulting products.

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The findings showed that the HFTU technique significantly impacted nutrient redistribution and reconcentration in the anatomical *S. bicolor* and *P. miliaceum* grains. In contrast, it showed that the technique adversely influenced the micromineral of the *P. miliaceum* grains, including whole grain (ground) resulting from the hummer milling and fractions (husked) resulting from the TM05C husker. The efficiency of the husking process was evaluated to be 87% for the concentration and redistribution of nutritional components and 60% for the fluctuation in mineral content dependent on the ratio of bran to endosperm. The approach decreased the thousand kernel weight (TKW) compared to whole grain, namely the endosperm (grits). Furthermore, the redistribution of the crude protein percentage indicated the accuracy of the HFTU technique, as it revealed an average variation ratio of 26.6% between the bran and endosperm in the dataset. Despite the overall dietary fiber content, the difference in TDF % ascribed to bran/endosperm was 10.9% in the case of sorghum grain attributed to various varieties and regions (Table 18). Conversely, the ash content of whole grains (hummer) and husked products (TM05C) rose by 33.2% compared to typical values of 15% and 21%, respectively. Additionally, this research revealed that the levels of minerals such as calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), sulphur (S), and zinc (Zn) in the bran and endosperm altered by 29%, 13%, 8%, 4%, 17%, 18%, 1%, 13%, 6%, and 12% respectively, during a period of 30s to 80s-time

units. The study found that the husking process significantly affected the colour profiles attributed to several sorghum grain varieties sourced from diverse origins (Tables 18 and 19). It can be interpreted that the HFTU is valuable and effective in optimizing the nutritional profile characteristics of sorghum grain products despite to variability of the variety of factors and origin source, which can lead to providing high-quality nutrition derived from sustainable sources.

On the other hand, The discriminant analysis (DA) results were consistent with the findings of (Khalfalla et al., 2024 and Rubio-Armendáriz et al., 2023). These researchers observed that the nutritional content of cereal grains varies depending on their origin (Figure 28). moreover, the findings aligned with a previous study(Rumler et al., 2022; Sruthi et al., 2021); the study outcomes indicated the influence of grain processing based on the variation in variety and region on the colour profile properties of the processed cereal grains.

The findings outcomes suggested that the HFTU process yields different characteristics in the produced fractions (bran and endosperm (grits)) compared to whole grain flour (ground). The process can deliver high-quality products that meet various dietary requirements. For example, the AS1 2021 IMI variety from Nyíregyháza is ideal for elderly individuals due to its abundant protein and iron mineral contents. On the other hand, varieties with high total dietary fiber are suitable for individuals seeking to meet their weight-loss dietary requirements.

The knowledge acquired during the husking process can serve as valuable guidelines for implementing the HFTU procedure. Additionally, smaller producers and processors can enhance the market competitiveness of sorghum products and promote environmentally sustainable production by adopting modern husking technology. Based on the findings, the study proposes developing products from the analyzed varieties through additional physical and chemical analyses. Moreover, conducting in vivo research is recommended to investigate the nutritional composition of the various sorghum varieties to obtain a comprehensive understanding of the benefits of the employed husking procedure.

Features of the employing time units:

When the dehulling time is shorter (30s), the outer hulls may not be completely removed, potentially leading to higher fiber content. As well as the finding could not fully enhance the availability of nutrients like proteins and essential minerals; it could be valuable in certain contexts. On the other hand, a longer dehulling time (80s) can more thoroughly remove the outer hulls, possibly resulting in a higher concentration of accessible nutrients such as proteins, vitamins, and minerals while reducing the fiber content.

Regarding the nutritional composition of the various cereal grains, the study explained that male sterility is a hereditary characteristic used to enhance hybrid seeds. However, it does not directly modify the grain's nutritional content, indicating that the sorghum grains can be affected by genetic factors and processing techniques after harvesting, as confirmed by the outcomes of Appendix 15 to 18 findings.

To draw attention to the superior varieties of Hungarian sorghum, which have adapted to various treatments, such as cultivation under N fertilizer conditions and applying the HFTU technique. Comparing the varieties has presented unique nutritional characteristics, sparking intrigue about being utilized as alternative benchmark varieties.

For a comprehensive assessment of *S. bicolor* and *P. miliaceum* nutritional properties, we performed a comparative evaluation of two sorghum varieties were involved Alföldi 1 (red sorghum variety) and Farmsugro180 (white sorghum variety), besides Biserka, Rumenka, and Gyöngyszem (*P. miliaceum* varieties). The comparative evaluation was attributed to variety cultivation under N fertilizer conditions, without N fertilizer treatment, based on mineral nutrients in the bran fraction and the endosperm (grits) fraction, as detailed in Figures (5 to 7). The evaluation can provide a good insight into the impacts of different treatments or processing conditions on the elemental profiles of the respective cereal grains, which can promote them as a nutritional benchmark for sorghum seeds cultivated under different environment zones.

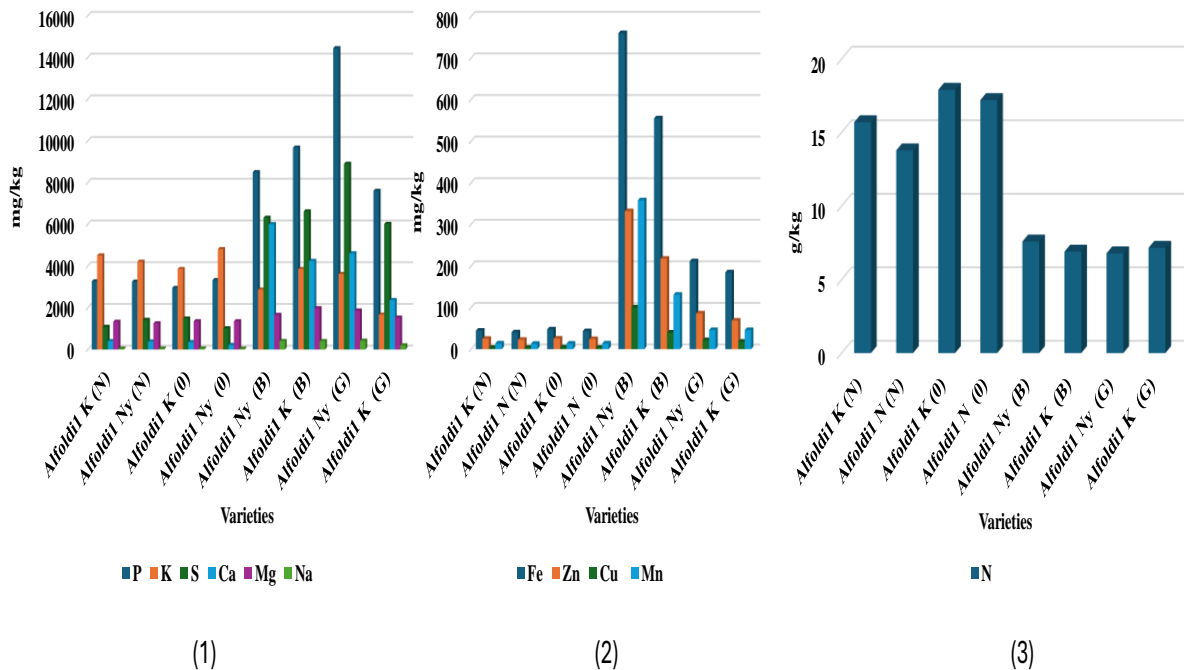


Figure 5. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Alföldi 1 (red sorghum variety) based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

Alföldi 1 (red sorghum variety) is a commonly cultivated sorghum grain variety in various regions in Hungary due to its unique nutritional characteristics, tolerance to climatic changes, and early-mid maturity time led to proper growth and development.

Here are partial nutritional properties evaluations, which can help us understand the influence of various treatments on the dietary compositions of common Hungarian sorghum grain varieties.

The findings showed that the highest P mg/kg content was recorded after the dehulling process in the endosperm (grits) within an average of 14442 mg/kg, as the highest noticed P mg/kg concentration among the processed sorghum grains. The result was evidenced by the responsiveness of the Alföldi 1 variety for the husking process, as described in Figure 29 ($P < 0.05$). Contrary to K mg/kg concentrations, when the lowest average of K mg/kg was noticed among the Alföldi 1 variety sourced from Karcag and Nyíregyháza regions, with an average of 1689 mg/kg and 1667 mg/kg, respectively.

Otherwise, the result of K mg/kg was similar to findings of Fe mg/kg content in the Alföldi 1 variety, when the highest average of Fe mg/kg concentrations were recorded after the husking Process.

Utmost supportive findings for the nutrient reconcentration can be addressed by N g/kg content in the Alföldi 1 variety, as indicated by the average values of Alföldi 1 K (0) whole grain, Alföldi 1 (B) bran fraction within 15.3 g/kg was reduced to 10.0 g/kg, despite of the mentionable reduction, the results has emphasized the implications of the husking process on nutrients redistribution and reconcentrate on the variety, referring to origin source Figure 28.

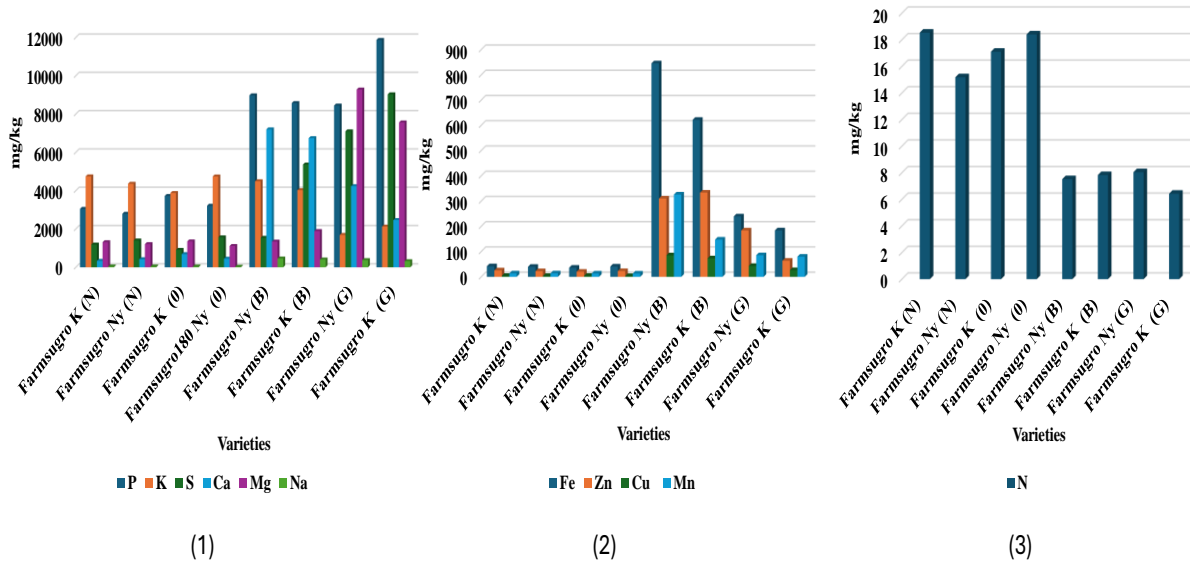


Figure 6. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Farmsugro180 (white sorghum variety) based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

The Farmsugro180 variety is a super sorghum grain resistant to high temperatures. It has a successful cultivation history in Hungary's southern regions. Therefore, we intend to report the findings of various cultivation experiences in Hungary's eastern (Karcag) and eastern-west (Nyíregyháza) regions.

The findings indicated that the elemental profile of Farmsugro180 was enhanced after the application of The HFTU process; for instance, the Nyíregyháza region has demonstrated the highest levels of Ca, Na, Cu, and Mn at 7199, 456, 85, and 326 mg/kg, respectively, as shown in Figure 28 with a significance value of $P < 0.05$.

On the other hand, the variety showed a negative range of a^* (red spectrum), referring to free coloration pigment (Tannin).

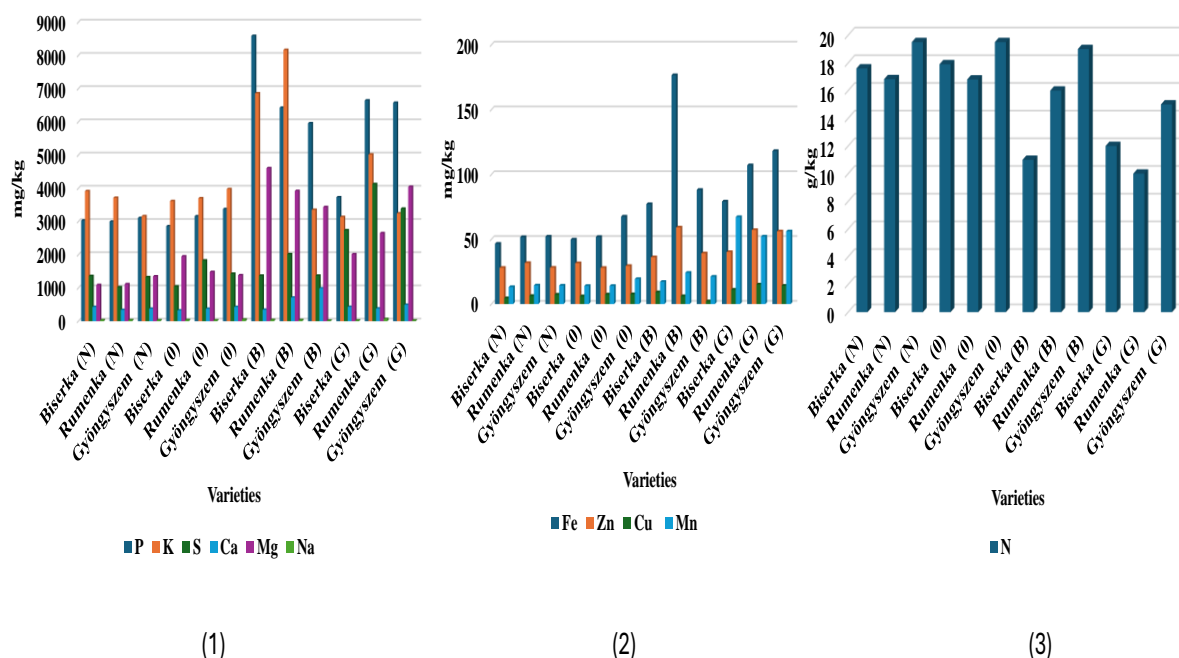


Figure 7. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Biserka, Rumenka, and Gyöngyszem based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

We evaluated the *P. miliaceum* nutritional characteristics attributed to various treatment circumstances, with a significance value of ($P < 0.05$). The calcium (Ca) mineral was unique evidence of the *P. miliaceum* investigation measurements, which was reflected in the lowest level of Ca mg/kg among the tested *P. miliaceum* varieties compared to the whole grains findings, the data was displayed in the Ca mg/kg contents in different cereal grain varieties and sorghum grain varieties after applying the HFTU technique, moreover the revealed level of Ca mg/kg was ranged from 344 mg/kg and 988 mg/kg as were demonstrated in the bran fraction. The finding was contrary to the revealed result of Fe mg/kg contents when the level of 176 mg/kg was recorded as the highest level of iron mineral among the dehulled *P. miliaceum* varieties (ground) compared to similar dehulled sorghum grain varieties from the different three regions in Hungary (Figure 1).

The findings showed that the Gyöngyszem variety has adequate crude protein and iron minerals.

Using a comparison approach, we conducted a comparative analysis between *S. bicolor* and *P. miliaceum* varieties. Specifically, we examined the N: S, P: Ca, K: Na, and Fe: Zn ratios in a dataset obtained from the HFTU of 30s and collection varieties sourced from Niryegehaza (sandy soil). The results of this analysis are outlined in Tables 6 and 7.

Table 6. Proximate comparative analysis for the dietary composition of the milling fractions of *S. bicolor* in the case of 30s time unit

Variables	Endosperm (grits)				Bran			
	N:S	P:Ca	K:Na	Fe: Zn	N:S	P:Ca	K:Na	Fe: Zn
Ny1	1:1	8:1	42:1	2:1	7:1	1:1	6:1	1:1
Ny4	13:1	7:1	35:1	2:1	1:1	6:1	107:1	1:1
Ny7	14:1	7:1	22:1	2:1	7:1	7:1	75:1	2:1
1/4 Ny	11:1	3:1	71:1	2:1	219:1	3:1	45:1	2:1
180 Ny	12:1	4:1	78:1	3:1	12:1	4:1	78:1	4:1

- The ratios were calculated and generated from the average values on a dry basis after unifying the total protein units

The results revealed diverse ratios of the essential nutritional components that may interact with an ordinary human diet. These ratios were seen across the chosen dehulled grain varieties.

Table 7. Proximate comparative analysis for the dietary composition of the milling fractions of *P. miliaceum* in the case of 30s time unit

Variables	Endosperm (grits)				Bran			
	N:S	P:Ca	K:Na	Fe: Zn	N:S	P:Ca	K:Na	Fe: Zn
Biserka	5:1	8:1	17:1	2:1	9:1	15:1	12:1	1:1
Gyöngyszem	5:1	7:1	39:1	3:1	9:1	4:1	20:1	2:1
Rumenka	2:1	9:1	22:1	3:1	11:1	4:1	22:1	2:1

- The ratios were calculated and generated from the average values on a dry basis after unifying the total protein units

The comparative strategy revealed that the HFTU technique favorably affected the redistribution and concentration of nutritional content in dehulled *S. bicolor* compared to *P. miliaceum* fractions, supported by the ratios reported in Tables 6 and 7.

The (HFTU) results were assessed for sufficiency and accuracy by comparing the protein level percentage accumulation in the bran and endosperm (grits) to a previous study conducted by (Pontieri et al., 2022). The authors elucidated the correlation between the protein content and the ripping stages, particularly emphasizing the protein content in the endosperm portion of inbred lines of varying ripping stages. The findings were accurate and precise, indicating that

Kafir races have a high protein content, with a range of (13%-18%). The findings confirm the investigation outcomes. (Rashwan et al., 2021); the author indicated the role of the dehulling process on processed grains, which can enhance protein and iron levels, vital components of the human diet. The findings were consistent with (Kumar et al., 2013). The investigation underscored the varied influence of the processing methods on the nutritional content's qualities. Although the iron (Fe) concentration was affected through the tearing phases, the research indicated a strong correlation between the grain's ripping stage and the composition of the nutrients. According to the study, the Alpha 4 race of sorghum race demonstrated that its protein content correlated with an iron concentration.

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The findings demonstrated that their high nutritional content distinguished the sorghum races under investigation. Specifically, the Kafir race exhibited a strong correlation between the associated minerals, including Ca: P, K: Na, and Fe: Zn attributed 80s time unit, with correlation coefficients of $R= 0.884$, $R= 0.745$, and $R = 0.893$, respectively, which makes it an advantageous candidate for potential product advancement.

Assessing the colour stability of sorghum seed inbred lines offers significant benefits, especially in agricultural, industrial, and commercial contexts. Here are some of the main advantages:

Colour stability may be a criterion for selecting better-inbred lines in breeding projects. Understanding the genetic basis of colour stability might provide vital knowledge about the

inheritance of other important characteristics. As support for the colour measurement precision, the results revealed that the tannic acid contents were associated with the finding outcomes of the Konica Minolta spectrometer camera, as presented in a varied range of Y, L*, a*, and b*. Enhancing the flavor, texture, and overall quality of sorghum-based meals might result in greater marketability and customer satisfaction with the resulting products. Accordingly, it can maintain the revealed features through the breeding programs. That can promote the nutritional profile of processed sorghum by providing good insight into the desired nutritional features and colour properties.

profiles, which can facilitate their introduction to the industrial sectors and promote scientific research based on an innovative husking approach to sorghum grain. By addressing advantageous aspects, we can encourage the improvement of the breeding program and discover and develop novel varieties.

4. Summary

According to the investigation's measurements and revealed results, the project outcomes emphasized the sufficiency and validity of the Hungarian soil for the *S. bicolor* and *P. miliaceum* grains cultivation when the assessment was designed based on the comparative approach through incorporating the main alternative *S. bicolor* and *P. miliaceum* grains in comparison to two common staple cereal grains such as winter wheat and oats. At the same time, the sample collection was performed and conducted attributed to soil type conditions. Those were progressively for the 2020 and 2021 cultivation seasons, highlighting the effective factors affecting the nutritional properties: variety and region (soil type). Addressing the essential factors can promote the mineral compositions of whole-grain raw materials. Contributing to facilitating the investigation measurements for whole grain nutrient contents under N fertilizer, without N fertilizer, and processed grains (dehulling), focusing on the factors that can affect the nutritional profile of the respective cereal grains.

While the project was designed to investigate and measure the suitability of *S. bicolor* and *P. miliaceum* for human consumption, the study objective was to employ sufficient techniques for processing *S. bicolor* and *P. miliaceum* grains. This can be reflected in reducing antinutrients and improving nutrient digestibility and viability, which could significantly impact human health.

Our investigations were concluded by a novel Husking Fraction Time Unit (HFTU) technique, which demonstrated remarkable effectiveness in enhancing the nutritional properties of the respective cereal grains. That involved crude protein, total dietary fiber, P, S, K, Ca, Cu, Mg, Fe, Na, Zn, and Mn, and colour stability assessments. The accuracy of the approach was assessed based on the homogeneity of diverse commercial grain varieties and regions, besides further measurements attributed to two sorghum races inbred line, namely *S. bicolor* and Kafir race. The technique applied to sorghum was set based on the 30s- and 80s-time units, showcasing its robustness and reliability.

Similarly, the HFTU technique, based on the 30s and 80s, was employed to improve the nutritional characteristics of *S. bicolor* grains. In comparison, the 30s and 50s time units were used to process *P. miliaceum* grains. For the precision goal, the *S. bicolor* findings were compared to *P. miliaceum* grain varieties and *S. bicolor* grain varieties acquired from the same production location. This comparison allowed us to draw meaningful conclusions about the nutritional properties of these grains.

Recorded implications and fluctuations in nutrients' composition varied and returned to the respective variety characteristics. Compared to ES Föehn (European sorghum benchmark seed), The Esztár production site has been designated as an international supplier of sorghum owing to its strategic location on the border between Hungary and Austria, specifically in the Northern Great Plain region of eastern Hungary. The area also features an international exchange center for sorghum research.

The findings generally indicated that the HFTU positively impacted the nutritional content of sorghum grain. At the same time, an adverse effect was noticed among some nutrients, such as the micromineral content of *P. miliaceum* grain varieties.

Additionally, the investigation significantly contributed to the sorting of the produced fractions (bran and endosperm (grits)), as evidenced by the nutritional properties and colour profiles variability attributed to the specific time unit, an instance of 80s, the employed time unit significantly impacted the reconcentration and redistribution of crude protein and iron mineral in the bran and verse impact revealed by 30s in case of endosperm (grits) of the *P. miliaceum* among the respective varieties, the property can offer a good insight to the diverse resulted fractions that can fulfill the various dietary group requirements and provide protective diet against un communicable diseases such as diabetic type 2, hypertension, and anemia, according to revealed results of nutritional compositions, the advantages resulting in husked fractions variability that can benefit foodstuff production include baby cereals, pasta, bread, and dessert, investing in the diversity of nutrient contents and color characteristics.

In our recent project studies, we aimed to thoroughly examine the accuracy of the HFTU procedure by dehulling the inbred lines of two sorghum races. The races were differentiated based on their distinct ripening time and colour characteristics. The significant advantage of the conducted collection measurements is that they allow us to identify and enhance the genetic traits of each race according to the desired nutritional properties associated with the HFTU linked to each variety.

The most notable finding was that the examined varieties exhibited stability and tolerance during dehulling, resulting in high nutrient content.

The research limitation can address two cultivation seasons, namely the 2020 and 2021 seasons. In addition, funding constraints confined the HFTU analysis to certain grain varieties. The HFTU was done by considering the particular nutrient contents, which necessitate further moisture content and physical and chemical examination of the previously studied and new varieties.

5. New scientific results

1. The study findings indicated that *S. bicolor* and *P. miliaceum* could be considered viable alternative cereal grains in Hungary, particularly in light of the 2020 and 2021 cultivation seasons outcomes, which highlighted and assessed their variable responses to N fertilizer, nutrient uptake, and nutrient accumulation in the grain tissue in comparison to conventional cereal grains such as winter wheat and oats.
2. N (CAN 27%) fertilizer can play a crucial role in activating or inhibiting specific mineral contents, such as calcium (Ca) and sodium (Na). When a noticeable reduction was observed in the loam clay soil after N fertilizer application compared to sandy soil, the findings indicated that the mechanism could depend on the soil type (production site) and the environmental conditions of the cultivation season.
3. The study found that the soil type significantly impacted the mineral composition of *S. bicolor* grains cultivated in the Karcag (loam clay) and Nyíregyháza (sandy) regions. This was evidenced by the correlation between the accumulation of phosphorus (P) minerals in the grains and the essential phosphorus (P) minerals found in the soil type (soil chemical components) of the original production site (region); the soil chemical components are presented in Table 1.
4. The conducted experiments demonstrated that the novel Husking Fraction Time Unit (HFTU) procedure substantially influenced the redistribution of nutritional concentrates within the mineral content of husked grain (TM05C) after the application of the technology, in contrast to ground whole grains (hammer). The results show that the novel HFTU procedure is affected by the diversity of grains and their geographical origin. The variable nutritional levels were ascribed to the used time intervals of 30 seconds, 50 seconds, and 80 seconds.
5. The research findings indicated that the HFTU procedure influenced the colour profiles of the dehulled grains, as shown by the colour parameter values. The results were compared to the tannic acid concentration in the whole grains of the assessed cereal varieties.
6. After undergoing the HFTU procedure, the milling fractions from both inbred sorghum races showed nutritional alterations, proving that the approach accurately separated the milling fractions.
7. According to the study's findings, *S. bicolor* and *P. miliaceum* can adequately provide a variety of nutritional needs. Critical mineral content analysis, which considered ratios

including N: S, P: Ca, K: Na, and Fe: Zn, offers credibility to this decision. K: Na is an outstanding illustration of the respective analysis. It is worth mentioning that the K: Na ratio showed a considerable negative association with all the research data, which highlighted its importance in the analysis. As co-factors and vital components of human metabolism, the analyzed mineral ratios are crucial indicators of cereal grain quality. It is important to emphasize the preservation of a proper diet balance.

8. The research project updated the nutritional profiles of the prevalent *S. bicolor* and *P. miliaceum* varieties adapted for cultivation in Hungary and the broader European region. This was achieved through a comparative approach that incorporated local, commercial, and inbred line sorghum grains. Accordingly, the study outcomes validated the main goal of the research target.
9. The research project analyzed and highlighted its contributions to sustainable development goals and food security, specifically Sustainable Development Goals 2, 3, and 12. These included achieving Zero Hunger, ensuring optimal health and well-being, and promoting sustainable production and consumption.



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Subject: PhD Publication List

Candidate: Maha Abdalla Rakaz Khalfalla
Doctoral School: Doctoral School of Nutrition and Food Sciences
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List of publications related to the dissertation

Foreign language Hungarian book chapters (1)

1. **Khalfalla, M. A. R.**, Zsombik, L.: Proximate assessment of crude protein content in Hungarian Sorghum (*S.bicolor* (L.) Moench) grain varieties.
In: Minőségvizsgálattól az élelmiszerbiztonságig / Máthé Endre, Sipos Péter, Szepesi Judit, Debreceni Egyetem Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar, Debrecen, 103-109, 2023. ISBN: 9789634905257

Foreign language scientific articles in international journals (5)

2. **Khalfalla, M. A. R.**, Zsombik, L., Györi, Z.: Assessing Crude Protein Levels and Microelement Concentrations of Flour Grain Yield of Sorghum bicolor (L.) Moench Cultivars.
Agrobiodivers Improv Nutr, Health Life Qual. 8 (1), 9-16, 2024. ISSN: 2585-8246.
DOI: <https://doi.org/10.15414/ainhlq.2024.0002>
3. **Khalfalla, M. A. R.**, Zsombik, L., Györi, Z.: Exploring Potassium and Sodium Composition in Hungarian Sorghum Grains as Key Markers of Cereal Grain Quality.
An. Uni. Oradea Fasc. Ecotoxi. Zoteh. Tehno. Industr. Alimentara. 23, 121-127, 2024. ISSN: 1583-4301.
4. **Khalfalla, M. A. R.**, Zsombik, L., Diósi, G., Györi, Z.: Implications of husking process on the nutritional composition of sorghum grains: diverse varieties and regions.
Int. J. Food Sci. Technol. 59 (6), 3760-3772, 2024. ISSN: 0950-5423.
DOI: <http://dx.doi.org/10.1111/ijfs.17117>
IF: 2.6 (2023)
5. **Khalfalla, M. A. R.**, Zsombik, L., Nagy, R., Györi, Z.: Promoting the elemental profile of sorghum grain: Driving factors affecting nutritional properties under nitrogen fertilizer conditions.
Heliyon. 10 (7), 1-21, 2024. ISSN: 2405-8440.
DOI: <http://dx.doi.org/10.1016/j.heliyon.2024.e28759>
IF: 3.4 (2023)





6. **Khalfalla, M. A. R.**, Zsombik, L., Györi, Z.: Revealing Consequences of the Husking Process on Nutritional Profiles of Two Sorghum Races on the Male Sterility Line.
Foods. 13 (7), 1-18, 2024. EISSN: 2304-8158.
DOI: <http://dx.doi.org/10.3390/foods13071100>
IF: 4.7 (2023)

List of other publications

Foreign language international book chapters (1)

7. **Khalfalla, M. A. R.**: Exploring the Impacts of Climate Change on the Nutritional Properties and Food Security of Various Cereal Grains.
In: Exploring the World of Cereal Crops. Ed.: Timothy J. Tse, IntechOpen, London, 1-14, 2024, (ISSN 3029-052X) ISBN: 9780854667482

Foreign language scientific articles in international journals (2)

8. **Khalfalla, M. A. R.**, Hussien, M. O., Ibrahim, H. M.: Isolation, Extraction, Purification, and Molecular Characterization for Thermostable α -Amylase from Locally Isolated Bacillus Species in Sudan.
Biochem Res Int. Epub, 1-8, 2021. ISSN: 2090-2247.
DOI: <http://dx.doi.org/10.1155/2021/6670380>
9. Abd-Ulgadir, K. S., El, T. A., Ahmed, H. H., El Shiekh, H. E., **Khalfalla, M. A. R.**, Abosalif, K. O., Abdelsalam, K. A., Satti, A. B.: An in vitro antimicrobial potential of various extracts of commiphoramyrtha.
Journal of Biomedical and Pharmaceutical Research. 4 (2), 15-19, 2015. ISSN: 2279-0594.

Foreign language abstracts (7)

10. **Khalfalla, M. A. R.**, Zsombik, L., Györi, Z.: Comparative Study of Calcium and Iron Elements in Proso Millet (*Panicum miliaceum* (L.) Whole Grain Varieties.
In: 11th International Conference on Agriculture and Food : Book of abstracts, Science and Education Foundation, Burgas, 93, 2023.
11. **Khalfalla, M. A. R.**, Györi, Z., Pál, V., Zsombik, L.: Correlation Between Crude Protein and Trace Elements in Common Buckwheat (*Fagopyrum esculentum* moencl L.) Varieties.
In: The 15th International Symposium on Buckwheat: Buckwheat for health, Institute of Soil Science and Plant Cultivation- State Research Institute, Pulawy, 80, 2023. ISBN: 9788375623987





12. **Khalfalla, M. A. R.**, Zsombik, L., Győri, Z.: Prospecting of nitrogen fertiliser effect on elements in [sorghum bicolor (L.) moench] grain hybrids.
In: "Interdiszciplinaritás a régiókutatásban XI." : Nemzetközi tudományos konferencia. Szerk.: Dajnoki Krisztina ; Filep Roland ; Horváth Adrienn ; Pierog Anita, Debreceni Egyetem Gazdaságtudományi Kar, Debrecen, 25, 2023. ISBN: 9789634905189
13. Zsombik, L., Győri, Z., **Khalfalla, M. A. R.**: Unravelling Factors Affecting Element Concentrations in Sorghum [Sorghum bicolor (L.) Grain Varieties: Implication on Human nutrition.
In: Sustainable and Innovative Solutions in Agriculture and Food Industry (SISAF'23) One Health approach. Szerk.: Veress Szilvia, Kocsisné Papp Mariett, Stündl László, Debrecen, 43, 2023.
14. **Khalfalla, M. A. R.**, Győri, Z.: Advances in Making of Bread from Gluten Free Sources and Impact on Human Health.
In: Leveraging on Research and Innovation for Sustainable Development. Conference Proceedings of the 2nd Postgraduate Students Conference (virtual). Eds.: Emmy Kerich, Samuel Lutta, Boniface Alkamoi, University of Eldoret, Eldoret (Kenya), 42, 2022.
15. **Khalfalla, M. A. R.**, Győri, Z.: Bioavailability of Magnesium in Selected Plant Sources.
In: 18. Magyar Magnézium szimpózium : Proram és összefoglalók. Szerk.: Takácsné Hájos Mária, Vojich Viktor József, Magyar Kémikusok Egyesülete, Magyar Magnézium Társaság, Budapest, 24, 2023. ISBN: 9786156018199
16. **Khalfalla, M. A. R.**, Győri, Z.: Evaluation of Mineral Concentrations in Hungarian Proso Millet (Panicum miliaceum L.) Varieties.
In: Wellmann International Scientific Conference : Book of Abstracts. Ed.: Orsolya Kiss, University of Szeged, Hódmezővásárhely, 51, 2022. ISBN: 9789633068601

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