

Thesis of doctoral (PhD) dissertation

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

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LIST OF ABBREVIATIONS

HFTU	<u>H</u> usking <u>F</u> raction <u>T</u> ime <u>U</u> nit
30s	30 <u>S</u> econd
50s	50 <u>S</u> econd
80s	80 <u>S</u> econd
WDS	<u>W</u> eight of <u>D</u> ry <u>S</u> ample
WOS	<u>W</u> eight of <u>O</u> riginal <u>S</u> ample
E1	ES Föehn variety sourced from the <u>E</u> sztár
Ny1	ES Föehn variety sourced from the <u>N</u> yíregyháza
H1	ES Föehn variety sourced from the <u>H</u> ortobágy
E4	ES Monsoon variety sourced from the <u>E</u> sztár
Ny4	ES Monsoon variety sourced from the <u>N</u> yíregyháza
H4	ES Monsoon variety sourced from the <u>H</u> ortobágy
E7	AS1 2021 IMI variety sourced from the <u>E</u> sztár
Ny7	AS1 2021 IMI variety sourced from the <u>N</u> yíregyháza
H7	AS1 2021 IMI variety sourced from the <u>H</u> ortobágy
SDGs	<u>S</u> ustainable <u>D</u> evelopment <u>G</u> oals
K180	<u>Farmsugro180</u> variety sourced from the <u>K</u> arcag
Ny180	<u>Farmsugro180</u> variety sourced from the <u>N</u> yíregyháza
Sz 180	<u>Farmsugro180</u> variety sourced from the <u>S</u> zeged
K 1/4	<u>Alföldi</u> 1 variety sourced from the <u>K</u> arcag
Ny 1/4	<u>Alföldi</u> 1 variety sourced from the <u>N</u> yíregyháza
Sz 1/4	<u>Alföldi</u> 1 variety sourced from the <u>S</u> zeged
Farmsuggro180 (N)	Farmsugro180 variety treated with <u>N</u> fertilizer
Farmsuggro180 (0)	Farmsugro180 variety without <u>N</u> fertilizer treatment
Farmsuggro180 (B)	Farmsugro180 variety <u>b</u> ran fraction
Farmsuggro180 (E)	Farmsugro180 variety <u>e</u> ndosperm fraction
Alföldi1 (N)	Alföldi1 variety treated with <u>N</u> fertilizer
Alföldi1 (0)	Alföldi1 variety without <u>N</u> fertilizer treatment
Alföldi1(B)	Alföldi1 variety <u>b</u> ran fraction
Alföldi1(E)	Alföldi1 variety <u>e</u> ndosperm fraction

1. Introduction

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, climate change exacerbation, population growth, and changing dietary patterns. 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 various 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 30, 50, and 80-time80 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 inbred 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 mineral 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 various 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. Literature Review

2.1. *S. bicolor* and *P. miliaceum* alternative cereal grains overview

The diverse nutritious food options can play a vital role in mitigating the risks to food security caused by environmental and societal pressures (Kołodziejczyk et al., 2018). The issue affects more than one billion individuals worldwide. Additionally, making these dietary changes can aid in the effort to diminish deforestation and the release of greenhouse gases (Seppelt et al., 2022). Millets are recognized as valuable crops in the context of environmentally friendly farming, secure food supply, and nutritious foodstuffs (Priya et al., 2023). Climate change harms sorghum agriculture since it impedes growth and reduces production due to increasing temperatures and heat stress (Chadalavada et al., 2021). Moreover, climate change impacts land and farming via several methods, including fluctuations in rainfall yearly, mean temperatures, heat waves, shifts in weed, insect, or microbial populations, worldwide modifications in atmospheric CO₂ or ozone levels, and the decline of the sea levels (Raza et al., 2019). Several adaptation tactics were used to ensure food security in response to climate change. These strategies include crop diversification, water storage, disaster preparedness, and utilizing superior crop cultivars (FAO, 2008; Raj et al., 2022). The European Academies Science Advisory Council (EASAC) released guidelines for agricultural practices that aim to enhance biodiversity, minimize tillage, and prioritize smallholder farms to promote more biodiversity and ecosystem services (EASAC, 2022). *S. bicolor* grains have nutritional benefits and a higher capacity to prosper in various environmental circumstances, offering them an ideal option to fulfill food security strategies (Hazmi et al., 2022). Nevertheless, grain output increased by 2700 million tons annually, meeting supply and demand requirements (Vila-Real, 2017). According to the United States Department of Agriculture (USDA), global production is expected to reach around 60.06 million metric tons by 2023 (Omer, 2023).

The European Union has historically used sorghum for animal feed and has noticed an increasing trend toward using it for human consumption and biofuels (Gaither & Cavazos-Gaither, 2020; Martin, 2016). In the 13th century, sorghum was introduced to Hungary as a staple crop because of its stress-resistance characteristics (Vásárhelyi, 2022). Despite the productive cultivation of sorghum, Hungary used a geographic decision support system to design its growing practices, topography, and soil quality (Jóvér et al., 2020; Kovács et al., 2010).

S. bicolor and *P. miliaceum* are rich in nutrient compositions, which prompted them to be used as alternatives to wheat and barley in gluten-free diets. They are cultivated using various farming methods and are important for ensuring food security, especially in areas vulnerable to the impacts of climate change (Taylor, 2018).

Winter wheat and oats are essential crops in Europe, particularly oats, with a considerable presence in central Europe and the Western regions (Jelínková et al., 2016). However, climate change is confronting the cultivation of winter wheat and oats with environmental obstacles. That can affect crop development, morphology, and nutritional value, causing yield losses of over 50%, as reported by (Farkas et al., 2021). Consequently, *S. bicolor* and *P. miliaceum* emerged as viable alternatives for cereal advances due to their resistance to adverse environmental conditions, reduced carbon footprint, and capacity to flourish in harsh environments (Saxena et al., 2018). Nitrogen fertilizer can influence nutrient management depending on the soil type conditions and variety characteristics (Khalfalla et al., 2024). It is imperative to conduct a nutritional comparison between alternative grains such as sorghum and millet and staple cereal grains to promote sustainable food systems' development (Nayik et al., 2023); substitute grains provide increased adaptability, facilitating the uptake of the nutrients from the soil to the plant, enhancing their utilization as plant-based proteins and nourishing foods procured from sustainable sources (Poutanen et al., 2022).

2.2. *S. bicolor* and *P. miliaceum* grains utilization globally

Sorghum crop is fifth among the common cereal grains in developed nations, after staple grains such as maize, wheat, rice, and barley (Khalifa & Eltahir, 2023). *S. bicolor* has different utilization needs, commonly used for feed and ethanol manufacturing, offering vital resources for various economic businesses flourishing in modern countries. At the same time, it is a staple food source in the low economic nations (Venkateswaran et al., 2018). These initiatives highlighted sorghum's applications in solving the deficiencies related to nutrition issues (Thilakarathna et al., 2022). On the other hand, *P. miliaceum* is a vital nutrient source and can secure hidden hunger. As well as have limited investments in Europe, such as bird feed (Geisen et al., 2021; Hassan et al., 2021). In the last decade, *P. miliaceum* processing gained a significant concern for human diet intake, emphasizing its value as a nutrient-dense, sustainable ingredient that can provide various food options and addresses problems related to food-based cereal grains supplements and food security (Das et al., 2019).

Sorghum grain can be used for various prevalent culinary raw materials, including beverages, syrups, porridge, bread, and pasta. Additionally, it serves as a foundation for several innovative gastronomic mixtures (Aguilar et al., 2023). That not less than unique healthful property of *P. miliaceum* for human dietary requirements (Narciso & Nyström, 2023).

Figures 1 and 2 demonstrate the worldwide production rankings of alternative cereal grain over ten years.

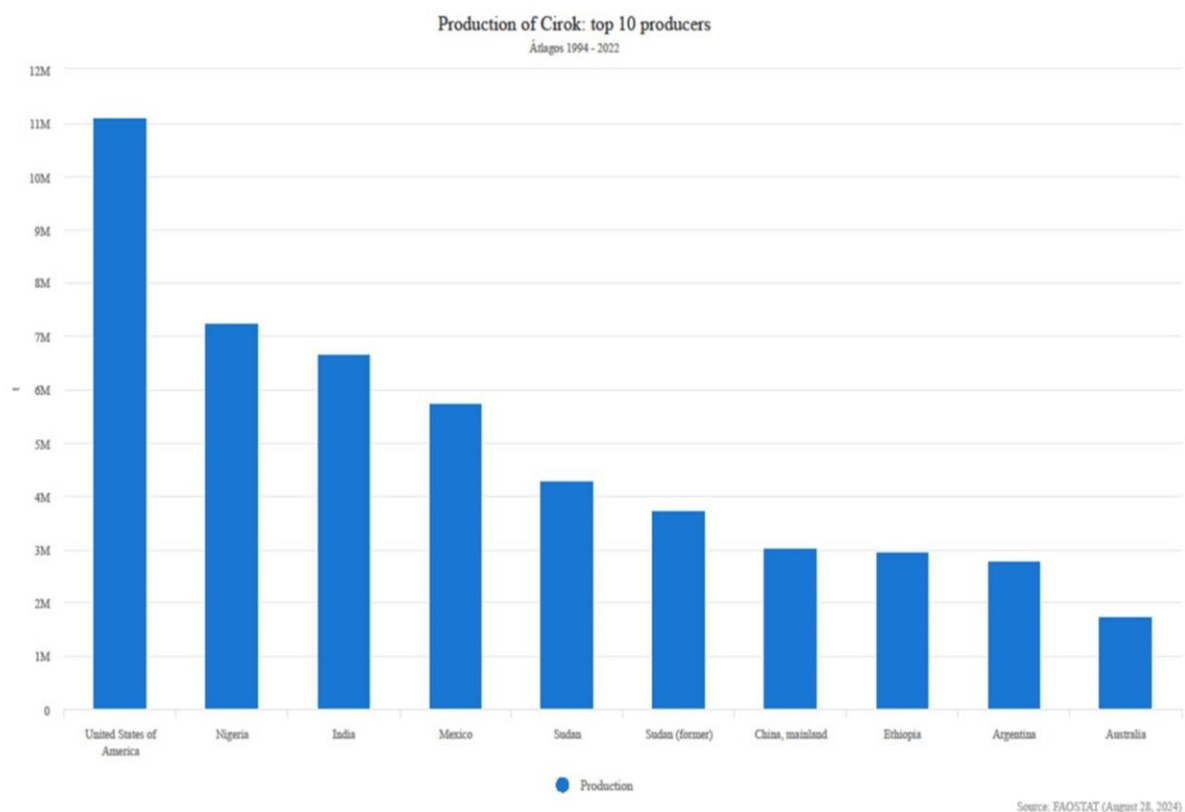


Figure 1. The worldwide production rankings of *S. bicolor* countries over ten years

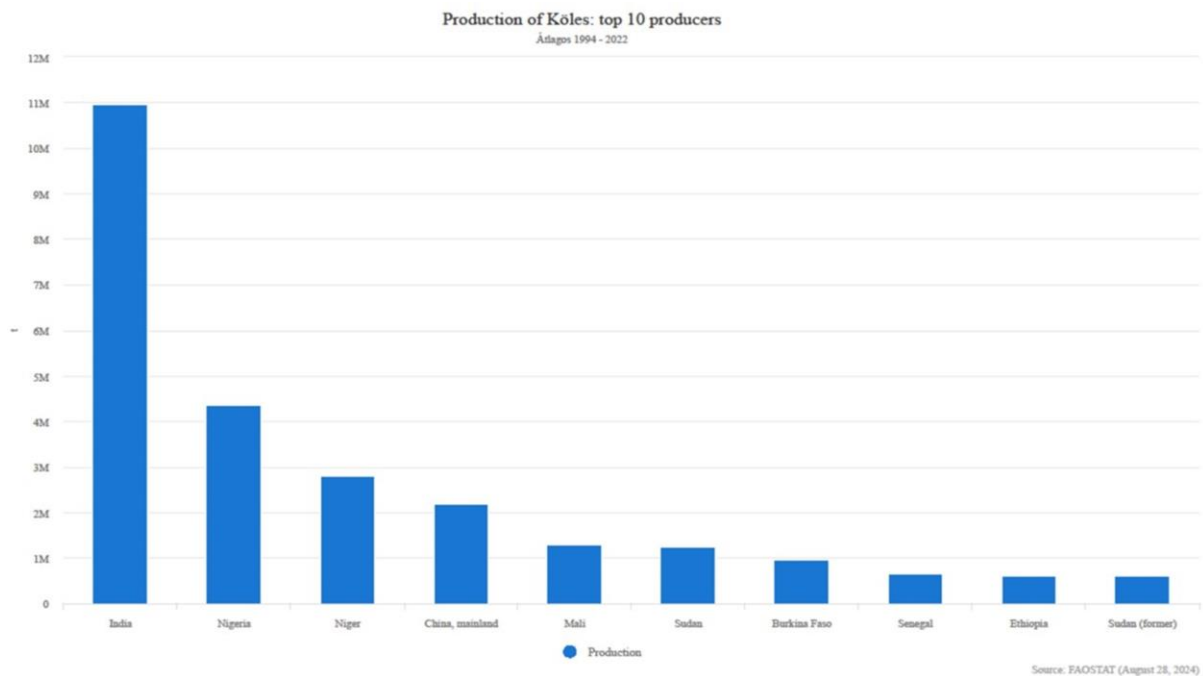


Figure 2. The worldwide production rankings of *P. miliaceum* countries over ten years

2.3. Consequences of the *S. bicolor* and *P. miliaceum* into SDGs and food security plans

Millets are essential sustainable crops as food resources since they contribute to food security and climate resistance. They demonstrate a vital in achieving the SDGs, for instance, SDG 2, which proposes eradicating hunger (Porwal et al., 2023). Millets can promote agricultural diversity by reducing dependence on staple grains, supporting sustainable farming methods, and mitigating risks such as pest infestations and soil degradation (Garg et al., 2018; Khalfalla & Györi, 2024). Moreover, millet cultivation can improve soil health and fertility by diminishing reliance on synthetic inputs and fostering sustainable agricultural practices such as crop rotation and intercropping systems. These actions can boost soil biodiversity and optimize the long-term viability of the production (Ventura et al., 2022). Millets possess drought-resistant characteristics and exhibit adaptability to water scarcity and nutrients (fertilizers) than conventional staple crops. Consequently, they play a pivotal role in places confronted with water supply issues (Wilson & VanBuren, 2022).

Millet processing possibly enhances the viability, accessibility, and concentration of nutritional components such as vitamins, minerals, fiber, and protein, contributing to the hidden hunger strategy's goals by providing healthy foodstuffs (Bhat et al., 2019). Moreover, Millet processing could combat hidden hunger, especially in contemporary areas where old methods fail to align with current lifestyle trends. Investing in millet processing and application

advancements may facilitate the attainment of the Sustainable Development Goals (SDGs), specifically, goal 3 for good health and well-being, such as poverty alleviation, sustainable resource management, climate resilience, and biodiversity preservation while supporting global food security initiatives (Seppelt et al., 2022).

International organizations and scientific investigations indicated that millet production meets SDGS 8 through the possibility of smallholders cultivating and repairing the surrounding areas, which can benefit poor lands, reflect economic advantages, and stabilize rural economies. Furthermore, millet's prolonged shelf life enhances food availability during periods of scarcity, ensuring year-round food security (Amadou et al., 2013).

2.4. S. bicolor and P. miliaceum Nutritional profiles based on the variety factor

Various variables, including the variety of sorghum grains, soil type, and environmental factor interactions, can significantly influence the viability of nutrients and the implementation of nutrient management strategies (Jat et al., 2013). However, previous scientific research has shown a significant correlation between crop varieties and the absorption of minerals that accumulate in the grain tissues, integrating a variety of genetic traits into breeding programs (Clark et al., 1990). Studies have shown considerable differences in nutrient levels and yield attributes across different sorghum genotypes (Kamal et al., 2023). Improving genetic varieties of sorghum, especially through the mineral fortifications, emphasized a critical role in the nutrient management program (Kondombo et al., 2024; Badigannavar et al., 2016). The genetic variation factor can promote food security and reduce hunger by reflecting on nutritional levels, considering the influence of the origin sources (Mut et al., 2022). Various techniques were used to transfer genes across different species to identify and choose superior varieties with favorable nutritional characteristics (Gaikwad et al., 2020; Parihar et al., 2021).

The researcher benefited from the variety diversity by employing it as a sufficient tool for cereal grain processing to nutrient management practices by selecting superior varieties with optimizing nutritional profiles and minimum amounts of antinutritional agents (Kudapa et al., 2023). The revealed diversity of sorghum grain varieties provided various applications in sorghum food and feed industries (Htet et al., 2022). The measured characteristics of various grain varieties varied depending on the desired patterns intended for application purposes, based on whole grain or processed grain diet, which led to a distinction approach between whole and processed grains (Tanwar et al., 2023).

The scientists were studying improved processing procedures for millets as food items, specifically focusing on understanding sorghum's structural and functional properties (Khoddami et al., 2023). Consequently, the categorization has made it easier to categorize the differences in nutrition between each grain's structure, motivating those interested in understanding the separation of milling fractions. Being thoughtful is a significant aspect in differentiating well-informed dietary need judgments. According to the research, whole-grain sorghum has been shown to provide essential nutrients and considerable health benefits. On the other hand, processed grain types are used for particular objectives based on their nutritional qualities. These goals include creating fractions, improving digestibility, and decreasing the presence of antinutritional compounds in the final products (Wang et al., 2022; Widowati & Luna, 2022).

Hungarian literature highlighted integrated categorization methods to showcase the extensive range of cultivated sorghum varieties effectively (Nagy et al., 2023; János et al., 2016).

The cultivation of sorghum has attracted significant interest from decision-makers in Hungary. The presented results enhanced the understanding of the agricultural environment and provided valuable knowledge on potential alternative methods and cereal grain production in the area. Comprehending the nutritional makeup of sorghum grains obtained from various production locations is crucial to fully exploit their potential as a food and feed resource in the Western world (Jóvér et al., 2018).

2.5. The distinction properties of husking fraction time units (HFTU) attributed to various employed time units per (second)

Hence, research and development approaches are required to enhance sorghum-based products' physical characteristics and nutritional properties (Deribe & Kassa, 2020). Resulting in grain processing as one of the strategies for improving the bioavailability of minerals in processed sorghum grain (Aslam et al., 2018). Previous studies outlined the urgent need for modern processing technology to enhance the quality of sorghum-derived foodstuffs, highlighting the common traditional treatments in the processing of sorghum grains (Aguilar et al., 2023; Abdelhalim et al., 2019; Taylor, 2018). These methods involved soaking, germination, fermentation, and technical processes such as heat treatments and irradiation to eliminate or reduce anti-nutritional components (Punia et al., 2021; Rashwan et al., 2021). Despite to process advantages, the most common traditional technique of processing sorghum grain consumes time. For instance, a recent paper on sorghum germination indicated that nutritional

improvements were seen after seven days of the procedure (Kayisoglu & Altikardes, 2024), confirming to literature as outlined sorghum processing issues addressing the inefficiency of germ removal and time-consuming, which can result in decreased shelf life and discoloration, ultimately impacting the quality and appearance of the final product (Khoddami et al., 2023; Li et al., 2022); hence, it is necessary to involve more effective time processing, as the (HFTU) procedure provides. Furthermore, modern grain processing equipment prioritizes environmental protection requirements and operational safety, ensuring a people-centric and sustainable approach (Lovegrove et al., 2023). The previous studies emphasized that the dry-fractionation approach is beneficial in enhancing the nutritional profile of cereal grains (Langó et al., 2018; Kołodziejczyk et al., 2018). Sorghum dry milling includes bran and germ removal, kernel breaking, and decortication milling (Khoddami et al., 2023). which were supported by (Proietti et al., 2013), the authors examined the impact of several parameters on the chelation characteristics, trace mineral levels, and bioavailability in sorghum food. In addition, sorghum ash content can indicate the mineral richness of the grains depending on the variety and anatomical parts (Adebo & Kesa, 2023).

Dehulling is among the simple grain processing procedures that act in removing the outer hull and impact the nutrient makeup of the remaining fractions, for instance, the bran and endosperm (grits); the distinguished features were highlighted as follows:

The bran fraction: Basically, the dehulling could cause a reduction in the antinutrient contents, such as phytic acid and tannins levels, in the grain bran (Adebo & Kesa, 2023). The bran fraction is rich in fiber contents and could be partially eliminated during dehulling. The remaining redistribution and reconcentration nutrient compositions vary depending on the accuracy of the employed husking process (Khalfalla et al., 2024; Oghbaei & Prakash, 2016). Furthermore, the bran portion has elevated quantities of minerals such as iron, zinc, phosphorus, and potassium compared to the whole grain and the endosperm (grits).

The endosperm fraction: Dehulling significantly alters the endosperm portion, resulting in a higher concentration of starch and carbohydrates. It also reduces fiber and antinutrients, potentially impacting starch digestion (Ikwebe et al., 2021)

Since most minerals are located in the bran layer, the endosperm fraction has lesser mineral contents than the bran; in contrast, the endosperm measurements showed that the husked fraction within an abundant crude protein level (Khalfalla et al., 2024).

The literature indicated that grain processing led to a decrease in TKW, which can be used as an indicator for re-electing the precision of the Husking Fraction Time Unit (HFTU) process (Sruthi et al., 2021).

2.6. *Characteristics of male sterility line of sorghum races on genetic trait and nutritional profile enhancements*

The male-sterile line approach is a genetic tool used in breeding for the desired genetic trait improvements. The scientist aimed to utilize the approach tool for sorghum grain genotypes, productivity, and agricultural characteristics that can contribute to the revealing of novel hybrids and nutritional quality targets (Tadesse et al., 2008; Chen et al., 2019). Prior research has documented many approaches to improving the quantity and quality of sorghum crops through breeding programs by investigating mechanisms for inducing male sterility lines (Htet et al., 2022; Chen et al., 2019). The approach showed achievements in the nutritional quality improvements of sorghum grain by Manipulated crossbreeding, infertile male crops, vegetative growth patterns, and reproductive habits. Accordingly, it is critical to comprehend the correlation between hulling and the nutritional properties of sorghum, particularly for those implied from male sterility lines:

Firstly, it guarantees the complete utilization of sorghum grains in the human diet and animal feed; the approach significantly influenced the nutritional profile optimization (Xin et al., 2017). Recognizing the connection between male sterility lines in sorghum breeding programs and grain processing techniques is vital for sustainable agricultural development, given the substantial influence of male sterility lines in these breeding programs (Saha et al., 2016). Inbred line varieties are essential for developing crop types with superior nutritional content and a high yield capacity (Kumar et al., 2011).

The African region, particularly the northeastern area, including Ethiopia and Sudan, is widely recognized as the most crucial and historically significant location for producing and preserving sorghum races, including the *S. bicolor* and Kafir races (Hurst et al., 2023). Several features can differentiate between both races, such as the protein contents; Kafir provides around 50-70% of the overall protein content in sorghum. However, the *S. bicolor* race has a comparatively lower average protein level in whole grain and flour samples, ranging from 11.80 to 17.48%. Prolamins are a category of alcohol-soluble proteins that are challenging to digest, including Kafirins (Khalfalla et al., 2024; Cuevas et al., 2023). Current research is focused on exploring various techniques, such as genetic modification and traditional and modern grain processing, including dehulling processing, to enhance the digestibility of sorghum proteins and improve the accessibility range of antioxidants (Meena et al., 2022).

The sorghum Kafir race frequently has higher calcium concentrations and lower magnesium levels than the *S. bicolor* race. Most mineral correlations are missing at comparable levels in the Kafir race (Mahdi Hassan, 2023).

2.7. Impacts of the husking process on the colour properties of sorghum inbred line

The hull or seed coat, often darker than the cotyledons can be eliminated, resulting in a uniform yellow, black, or red color that is visually pleasing for consumption (Singh et al., 2024). *S. bicolor* and *P. millet* have distinct pericarp colors, including white, black, and red. Due to the presence of flavonoids in the aleurone layer and the grain's seed coating, these alterations could affect the nutritional and antioxidant properties (Nayik et al., 2023). Genetic regulation largely controls the colour of cereal, with numerous alleles regulating the grain's colouring (Kumar et al., 2011).

Genetic regulation largely controls the colour of cereal. The colour variability characteristics of *S. bicolor* and *P. miliaceum* are essential due to their useful insights into their nutritional composition, compatibility with processing processes, and appeal to consumers. Therefore, they impact their usage in estimating the final product's nutritional characteristics and promoting cereal industry sectors (Sruthi et al., 2021). Prior investigations have shown the effectiveness of time-unit processing on the nutritional attributes of sorghum (Souza et al., 2022). The findings of the nutritional profile qualities necessitated the importance of colour measurement for the investigated inbred line sorghum races. Furthermore, it provides valuable information for food processing companies to develop successful food processing businesses that limit nutritional loss. The Konica Minolta CR-410 colorimeter is used for general colour classification, and its results are presented as relevant findings (Steinberg et al., 2020).

2.8. Processing of *S. bicolor* and *P. miliaceum* for a healthy diet

The increasing recognition of millet as a nourishing food option has led to a concentration on grain processing techniques to enhance the accessibility and attractiveness of millet products for consumers (Saraswathi & Hammeed, 2022). Prior research emphasizes the immediate need for advanced processing technologies to improve the quality of food products made from millet grain sources (Aguiar et al., 2023; Taylor, 2018). However, millet processing techniques may improve nutrient digestibility, taste, and availability. However, it is important to consider nutrient losses to preserve the nutritional value and health advantages (Gowda et al., 2022).

The procedures used included soaking, germination, fermentation, and technological approaches, including heat treatments and irradiation, to eradicate or diminish anti-nutritional constituents (Punia et al., 2021; Rashwan et al., 2021). The scientific community highlights the dry-fractionation method's advantageous effects on improving cereal grains' nutritious composition while being environmentally friendly (Langó et al., 2018; Kołodziejczyk et al., 2018). Sorghum literature highlights issues with sorghum processing, including inefficiency, time consumption, and potential shelf-life loss, which affect product quality and appearance (Khoddami et al., 2023; Li et al., 2022). The consideration of grain processing promoted the dehulling process, and innovative new techniques were necessitated due to several issues implicated by the disadvantages of common processing procedures.

Table 1. Recommended daily allowance for human age groups

Variables	Daily Intake mg/100g Grain	RDA/AI (mg/day)-F	RDA/AI (mg/day)-M	% Intake - F	% Intake - M
P	308.06-678.19	700	700	44-97	44-97
K	96.35-232.26	2600	3400	4-9	3-7
Ca	8.01-19.00	1000	1000	1-2	1-2
Mg	57.58-92.74	320	420	18-29	14-22
Cu	0.12-0.30	0.90	0.90	13-33	13-33
Fe	1.36-3.37	18.00	8.00	8-19	17-42
Zn	1.32-2.54	8.00	11.00	17-32	12-23
Na	0.30-0.54	1500	1500	0	0
Mn	0.47-1.31	1.80	2.30	26-73	20-57
Cr	0.01-0.06	0.025	0.035	32-228	23-163

*RDA: Recommended Daily Allowance, AI, Adequate Intake, M: male (31-50 years), F: female (31-50 years). Source: (Jaćimović et al., 2023).

2.9. The correlations and interactions of nutrient components of the cereal grains

Cereal grains encompass nutrient components that could interact with one another regarding absorption, metabolism, and whole nutritional value (Meenaaz & Fathima, 2023). We address numerous nutrients that are included in the research project:

Protein: Protein-based seeds, a significant trend in transforming food systems, have great potential to promote a sustainable and nourishing cycle in the food system (De Ron et al., 2017). Various cereal grains may significantly enhance your choice of plant-based protein

sources. Due to their protein quantity levels and nutritional density, they are classified among the top-ranked outstanding dietary supplements (Banta et al., 2021).

Protein quantities can estimate the impact of dough flexibility and its water absorption capacity. The interaction between the protein component and mineral contents, namely calcium and magnesium, may affect flour's baking properties through their effect on its capacity to retain gas and texture during fermentation of the baked products (Helal et al., 2022).

Total Dietary Fiber:

Several cereal grain sources can provide unique dietary fiber supplements. For instance, oats are known to have a significant amount of soluble fiber, perhaps enhancing the absorption of nutrients and reducing cholesterol levels. However, whole wheat is distinguished by highly insoluble fiber, which can improve digestion and also can act as a hinder or inhibitor for mineral absorption if consumed excessively (Meenaaz & Fathima, 2023).

Minerals:

Understanding mineral interactions is essential for optimizing dietary intake, balancing inadequacies, and increasing nutrient absorption. Eating well-balanced meals with adequate iron, calcium, phosphorus, and potassium can maintain general health (Dotto et al., 2019). The flour mineral components could impact its nutritional value and functional properties, and the employed processing technique could affect the mineral levels and optimize the flour quality. Calcium enhances dough stability, while iron and zinc are vital for human health (Yang et al., 2018; Guttieri et al., 2015).

A wide range of phenolic compounds, such as condensed tannins, adequately protect the sorghum grains (Palacios et al., 2021). While tannins constitute around 19% of the overall phenolic components in sorghum as an ingredient in the diet (Wu et al., 2012).

Therefore, the content of tannins in *S. bicolor* can fluctuate from 0.10 to 3.60% by weight (m/m), according to (Asropi et al., 2022), with darker cultivars often exhibiting higher amounts. *P. miliaceum* has a lower tannin content than sorghum. The tannin concentration in *P. miliaceum* fluctuates from insignificant to 0.2% by weight (m/m).

Various treatments or processing methods could efficiently decrease the tannin concentration in sorghum grains (Mimich et al., 2018).

3. Material and Methods

The study involved two categorizing cereal grain collections based on soil types. The research followed an experimental design, collecting 250 sorghum grain samples. Overall, the collection included 20 samples of winter wheat, 20 samples of oats, 20 samples of *P. miliaceum*, and 250 samples of sorghum, which were collected from different sorghum production sites in Hungary (Figure 3), the first collection of the diverse cereal grain were cultivated under nitrogen fertilizer conditions in sandy soil, and involved the evaluation of the 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 tannic acid level measurements.

The second collection comprised commercial sorghum grain varieties from different production sites (regions) in Hungary. Experimental measurements included total dietary fiber, ash, protein, essential minerals, and tannin contents. The ES Föehn, Alföldi 1, and Farmsugro180 varieties were involved in various project investigations, such as cultivation under N fertilizer, attributed to soil type factor and the husking process measurements. Figure 4 demonstrates the red variety (Alföldi1) and white variety (Farmsugro180) grain colour and morphology.



Figure 4. The sorghum grain cultivation under N fertilizer conditions, the figure demonstrated the red variety (Alföldi1) and white variety (Farmsugro180)

On the other hand, the ES Föehn variety was employed as a sorghum benchmark for the nutritional properties of the sorghum grain varieties collections 1 and 2 of the cultivation under N fertilizer conditions and applications of the HFTU on the commercial cereal grains from different production sites (Figure 3).

Lastly, considering the implications of husking process measurements, we designed the third collection to ensure the precision of the HFTU process by employing two sorghum races (*S. bicolor* and Kafir) on male sterility inbred line into dehulling process experiments.

The research design was carefully selected and balanced to encompass common regions for sorghum production in Hungary. Therefore, the comparative approach is set up for a comprehensive evaluation of the stable cereal grain nutritional quality compared to the alternative cereal grains under commonly followed agricultural practices in the targeted regions.

Accordingly, regularized investigations were promoted to investigate the suitability of *S. bicolor* and *P. miliaceum* for human consumption as healthy, sustainable food sources, ensuring their validity through the nutritional and colour profile investigations, which were indicated by the accreditation measurement procedure for nutrient contents such as total dietary fiber, ash, crude protein, K, S, P, Fe, Ca, Zn, Mg, Na, Mn, and Cu.

Furthermore, the same techniques were utilized for the sorghum inbred line races (Table 5). The investigation was conducted to ensure the precision and validation of the HFTU technique on separation fraction sufficiency, as the results and discussion sections will explain later.

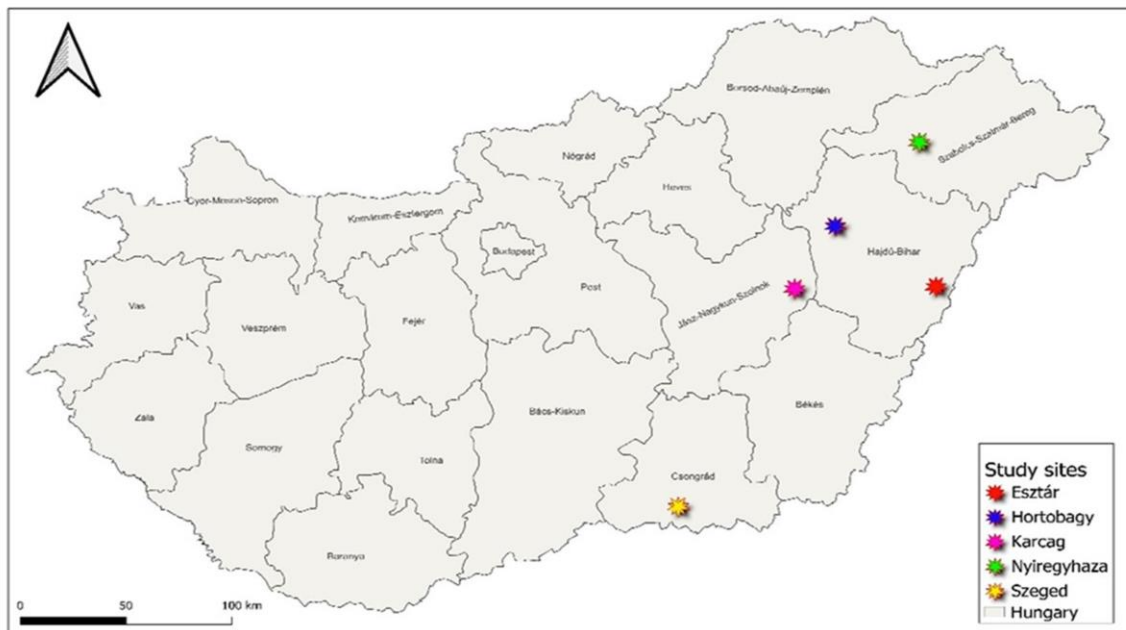


Figure 3. Description of sorghum grain varieties experiments and collections sites in Hungary

3.1. Investigation of diverse cereal grain under N fertilizer controlling

3.1.1. 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 2. 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
($\text{NO}_3 + \text{NO}_2$)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.

Table 3. Collection of sorghum grain varieties and comparative cereal grains cultivated in various production sites

Variety	Production site (Region)	Soil type	Ripping time	Grain colour
ES Föehn	Nyíregyháza	Sandy	Early	Red
Alföldi 1	Nyíregyháza	Sandy	Early	Red
ES Albanus	Nyíregyháza	Sandy	Semi late	White
Albita	Nyíregyháza	Sandy	Early	White
Farmsugro180	Nyíregyháza	Sandy	Semi late	White
ES Föehn	Karcag	Loam clay	Early	Red
Alföldi 1	Karcag	Loam clay	Semi-Early	Red

ES Albanus	Karcag	Loam clay	Semi-late	White
Albita	Karcag	Loam clay	Semi-late	White
Farmsugro180	Karcag	Loam clay	Semi-late	White
Winter wheat (SE 15)	Nyíregyháza	Sandy	Early	White
Oats (Lota)	Nyíregyháza	Sandy	Semi early	White
Biserka	Nyíregyháza	Sandy	Semi late	Yellow
Rumenka	Nyíregyháza	Sandy	Early	Red
Gyöngyszem	Nyíregyháza	Sandy	Early	White

According to Table 3. the chemical composition of loam clay (acidic soil) and sandy (alkaline soil) in Karcag and Nyíregyháza production sites, when the data presented variations attributed to soil properties in each region, estimating the factors affecting the elemental profile of the investigated *S. bicolor*, *P. miliaceum*, Winter wheat, and oat, which attributed to the revealed results of the diverse cereal grains experiment under N fertilizer conditions.



Figure 5. Sorghum crop in westik field, Institute of Nyíregyháza

3.2. Agrotechnical and meteorology of the diverse cereal grains

The agricultural practice of sorghum grains was started on May 13, 2020, seeding took place in the middle of May, depending on the weather at the Karcag location. The weeds were hand-pulled, and the harvest was conducted on October 15, 2020. At the start of the growing season, the multiannual average was 17.8 mm, less than the multiannual average of 54.2 mm. Additionally, the temperature was lower than 14.6°C than the multiannual average of 16.6,°C, which delayed the crop's initial stage of development. The crop's growth has benefited from

the significant rainfall that fell in June and July, particularly in the lead-up to the October 15, 2020, harvest stage.

The seeds were sown on May 13, 2021, about the 2021 growing season. They were adjusted when the average precipitation 73.6 mm, exceeded the multiannual average of 54.6 mm. Concurrently, the temperature of 17.5°C exceeded the yearly average of 16.3°C.

The weather at Nyíregyháza, on the other hand, was quite different. The sowing date 2020 was May 2, 2020, and the average precipitation for the 2020 season was 92.2 mm, less than the long-term average of 525.6 mm. During the vegetative phase, the moisture content was measured at 71%. May 2021 was the driest weather condition, with 82.8 mm of precipitation at the start of the growing season, less than the multiannual normal of 573.3 mm. On October 10, 2021, the 2021 harvesting season began. The two cultivation locations have varying climatic conditions for the production of *S. bicolor*, with more fall down during the vegetative phase and just before harvesting, offering beneficial circumstances; however, the fluctuations in water availability limited crop development and early emergence.

At the same time Nyíregyháza production site was involved in the agricultural practices for winter wheat and oat cereal grain crops began on October 02, 2019, with a sowing rate of 200 kg/ha⁻¹ on October 15, 2020, followed by fertilization on February 22, 2020, and concluded with harvesting on July 12, 2020. Conversely, the agro-technical processes for *P. miliaceum* and *S. bicolor* started with soil preparation after the harvesting period of winter wheat and oat crops on March 11, 2019. The harvesting period for *P. miliaceum* was on May 25, 2020, while *S. bicolor* harvesting was conducted on October 15, 2020.

Regarding the 2021 cultivation season, winter wheat and oats were sown on October 18, 2020, and harvested on July 16, 2021. *P. miliaceum* was sown on May 24, 2021, and *S. bicolor* on June 05, 2020. Consequently, the harvesting time for *P. miliaceum* was on September 27, 2021, and for *S. bicolor*, it was on October 10, 2021.

3.3. Investigation of the commercial varieties from various regions

Collection No. 2 consisted of 150 samples of sorghum grain kinds obtained from five distinct supplier firm locations in Hungary. The areas where the sorghum grain varieties were supplied from included Szeged (GK and KWS) and other suppliers in Nyíregyház, Esztár, and Hortobágy. The eight sorghum grain varieties were named ES Föehn, Gustav, ES Alize, ES Monsoon, ES Shamal, KWS Nemesis, AS1 2021 IMI, and AS2 2021. The ES Föehn, ES Monsoon, and AS1 2021 IMI varieties) and three *P. miliaceum* varieties (Biserka, Rumenka,

and Gyöngyszem). The respective varieties were selected to be included in the HFTU process. The comparison was made between these selected varieties and commercial whole grain flour, husked sorghum, and *P. miliaceum* products obtained from a local retail store (Appendix 1). Additionally, the ES Föehn variety was used as a benchmark sorghum seed.

3.4. Investigation of sorghum grain varieties inbred lines

Collection No. 3 targeted 51 samples of inbred lines from two distinct sorghum races, particularly *S. bicolor* and Kafir. These were distinguished according to two colour ranges (white and brown), as demonstrated in (Figure 5) and various ripening stages (appendix 2 and 3). The varieties originated from the Karcag breeding house in Karcag.



Figure 5. Part of the distinct collections of sorghum races from the Karcag breeding house

3.5. Reagents and equipment

3.5.1. 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.

3.5.2. 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)

3.5.3. 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.

3.5.4. Spectro colorimeter digital camera

Konica Minolta, Chroma Metre (CR-410, 2002) originated from Minolta Co. Ltd. (Japan).

3.6. Methods and accreditation procedures

3.6.1. Thousand Kernel Weight measurements

The kernels are weighed and counted. Weight data is collected via scales, whereas kernel calculating is conducted manually. To calculate Thousand Kernel Weight (TKW), divide a typical sample of seeds into ten of each 100 seed groups. Each set of 100 seeds is then weighed on a properly calibrated scale, and the total weights are totaled to get the TKW value. This measurement is critical when considering differences in seed size across different varieties and regions.

3.6.2. Dry matter measurements

The subsequent stages measured the dry matter content:

Drying step: We set an oven at 130–135 °C and dried the sample until it set up on a consistent weight. This 100% eliminates the moisture content of the samples.

Measuring the dehydrated sample weight: We carefully removed all samples from the oven.

We weighed the dry sample according to the standards outlined in (AOAC, 2016;

Hellevang, 1995), then the dry matter content was calculated by applying the desired following formula:

$$\text{Dry Matter Content (\%)} = \frac{\text{WDS}}{\text{WOS}} \times 100$$

WDS: Weight of dry sample

WOS: Weight of original sample

3.6.3. Preparation for the nutrient level measurements

The samples underwent measurement at the Central Chemistry Laboratories of the University of Debrecen. Before analysis, the samples were dried and finely ground using the Retsch SK-3 hammer mill with a 1 mm sieve. Ensuring uniformity through proper grinding was key to obtaining accurate and consistent analytical results. We performed and compared the processed whole grains obtained via the hammer mill with the husked grain for the results. Additionally, two processed grains (*S. bicolor* and *P. miliaceum*) underwent all the procedural steps.

3.6.4. Detection of the crude protein levels

We examined the nitrogen levels in the samples using the Kjeldahl method outlined in (ISO 20483:2013). This method involves several steps: digestion, distillation, and titration.

First, we treated the samples with concentrated sulfuric acid (H_2SO_4) and a catalyst ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) in specific proportions to convert nitrogen molecules into ammonium ions.

During digestion, ammonia was produced and evaporated, then collected in a solution containing boric acid (H_3BO_3) during distillation.

To measure the nitrogen content precisely, we titrated the collected ammonia with a standardized acid, typically hydrochloric acid (HCl).

We used 6.25 as the nitrogen-to-protein conversion factor to determine the protein content based on nitrogen levels. The resulting protein content is expressed as a mass fraction percentage of the dry product.

3.6.5. Determination of the total dietary fiber contents

We used the enzymatic-gravimetric method to measure dietary fiber. The method extracts starch, protein, and fat from grain samples to obtain a dried residue, which is subsequently weighed. We adjust for remaining protein and ash levels, and the final result is expressed as a ratio of the original material. This approach adheres to the specifications outlined in AOAC

985.29 and AACC 32-07.01, which numerous countries have widely adopted as the standard procedure for dietary fiber analysis. The procedure was applied according to Megazyme (2017).

3.6.6. Determination of ash contents

We measured the crude ash content of a sample. We started by burning it at 550°C and then measuring the residue remaining, expressing it as the sample's weight %.

We weighed 4 grams of the finely blended test sample with precision to the nearest 0.001 gram and placed it in a preheated and cooled ash pan.

Next, we heat the crucibles in an annealing furnace at 200°C for an hour and 550°C for three hours. We evaluate the carbon residual and restart the annealing procedure according to the procedure steps (AOAC, 2016).

After the cooling stage in a desiccator, we use a precise analytical balance for the weight of the crucibles.

Accordingly, we utilize the desired formula:
$$\text{ash\%} = \frac{(M3 - M1)}{(M2 - M1)} \times 100,$$

where M1 = initial mass of the crucible

M2 = crucible mass of the sample

M3 is the mass of both crucible and ash.

* The formula used after combustion is detailed in (AOAC, 2016).

3.6.7. Determination of the mineral components

We employed the accreditation procedure by using an authentic wheat sample known as BCR CRM 189 (whole grain), as described by (John & Taylor, 2023) These measurements were carried out according to multiple rounds, as described by (Kovács et al., 1996). As follows:

For our analysis, we utilized inductively coupled plasma optical emission spectroscopy (ICP-OES) technology (Figure 6); we conducted element measurements at specific wavelengths: phosphorus (P) at 177.495 nm, potassium (K) at 404.721 nm, calcium (Ca) at 183.034 nm, sulfur (S) at 183.801 nm, magnesium (Mg) at 285.204 nm, sodium (Na) at 330.237 nm, iron (Fe) at 238.204 nm, copper (Cu) at 324.754 nm, zinc (Zn) at 213.856 nm, and manganese (Mn) at 259.373 nm,

We weighed 1 gram for each sample and subjected it to aqueous acid digestion, which involved predigesting and digestion phases. After adding 10 ml of nitric acid (HNO₃, 69% v/v), we

heated the samples at 60°C for 30 minutes using a model block digestion apparatus (MIM OE-718/A). Then, 3 cm³ of hydrogen peroxide (H₂O₂, 30% v/v) was added, and the samples were further heated to 120°C for 90 minutes in the primary digestion stage. After cooling for 10 to 20 minutes, we increased the volume to 50 cm³ using ultra-pure water. Finally, we purified the homogenized suspension using an MN 640W filter paper. The concentrations of elements were expressed on a grain dry-weight basis (mg kg⁻¹).



Figure 6. The elemental composition detection in various grain fractions by using the ICP-OES technique

3.6.8. Application of the dehulling process

In the pre-stages of the study investigation, we utilized The Zaccaria PAZ-1/DTA rice mill 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, 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 μ m). 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.

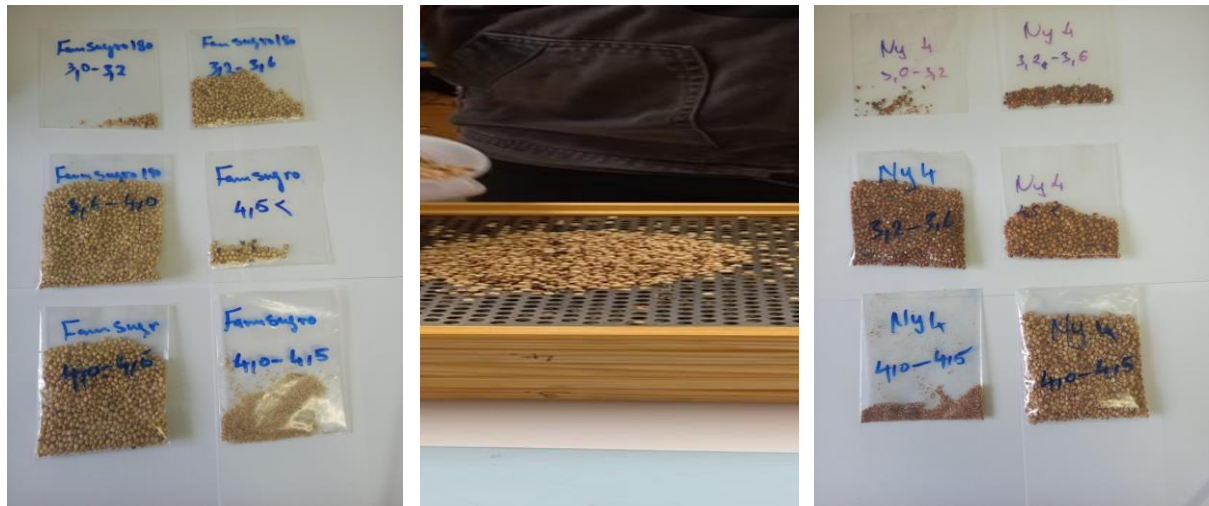


Figure 8. Preparation and optimizing the kernel diameter for the husking technique



Figure 9. 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.

3.6.9. Measurements of the colour profiles

We utilized a colorimeter, specifically the Chroma meter model CR-410 by Minolta Co. Ltd. in Japan, to measure the color attributes of the husked grains. These attributes include L^* (representing whiteness), a^* (for redness), b^* (for yellowness), and Y (for brightness), as outlined in the specifications provided by Konica Minolta's 2002 model, as presented in Figure 10.



Figure 10. Measurement of the colour profile of the respective grain varieties by utilization of CR-410 Konica Minolta Camera

3.6.10. Measurement of tannic acid contents

Cereal Chemistry (Herald et al., 2014) used a UV spectrophotometer (May & Burns, 1971), and revised the vanillin-HCL test protocols for detecting tannin. After measuring 1 g of the sample in a test tube with a screw lid, 10 ml of a solution containing 1% hydrochloric acid in methanol was added to the tube along with the sorghum grains. The sample was then shaken on a mechanical shaker at room temperature for 24 hours, and the tube was centrifuged for 5 minutes. Divide the liquid above the sediment into two parts: one containing 1 ml and the other containing 5 ml of vanillin-HCl reagent. Following a reaction period of 20 minutes, the sample was assessed for the intensity of its colour using a UV-visible spectrophotometer configured to measure absorbance at a wavelength of 500 nm. The grain colour variability is demonstrated in Figure 11.



*The photo presented the colour variation of red cereal grain varieties, selected randomly from the examined grain varieties.

Figure 11. Tracking the changes in the colour characteristics of the examined grains attributed to the Husking fraction based on time units compared to whole grain colour.

3.7. Statistical analysis measurements

Nature of the data set: I employed the data normal distribution for independent data set collections, as the variability distinguished the data due to various collection conditions, attributed to N fertilizer of the divers reported cereal grains (Table 2), collection without N fertilizer treatment (Appendix 1), collection of two sorghum races inbred line (Appendix 2 and 3), and the dehulling process findings outcomes, the values were presented as averages resulted from three reading replication (Tables 14 to 17) of the dehulling technique results and the statistical analysis tests were proved that diverse data set were following gaussian curve (positive normality test), according to (Chatfield, 1989). For the data sorting procedure.

Descriptive data analysis: The Descriptive data was utilized to show the sample size of the original data results of the comparative analysis of diverse cereal grain attributed to the sandy soil (Table 12) and for the commercial whole grain flour (ground) data set (Appendix 4 to 14), which involved three replications of mineral measurements with the units reported as mg/kg, while two replications of readings for total protein, total dietary fiber, and ash with the units reported as g/kg, and the descriptive data based on the average were conducted for the thousand kernel weights (g) and the tannic acid contents, as were presented as the (average) resulted from three replication readings.

ANOVA analysis model: I employed ANOVA One Way and ANOVA Two Way to discover the variance among the respective data sets by utilization (SPSS 28 software) program for the data set of factors affecting and promoting the nutrient composition of the diverse cereal grain and sorghum grains under N fertilizer conditions Tables (4-9), the husking process based on various varieties and regions (Appendix 4 to 14), and the data set of the husking process based on the sorghum race inbred line (Appendix 15 to 18).

Linear regression: The linear regression was performed to assess the colour spectrum and mineral content (most interact and associated minerals in the human diet) correlations variance and ascertain the statistical significance at a significance level of $P \leq 0.05$ (Smith, 1998).

On the other hand, the discriminant analysis test was created to distinguish the mean-variance based on the varieties and origin source.

Discriminant analysis: Based on the variety and region factors, the analysis was performed to detect the correlation between *S. bicolor* and *P. miliaceum* after HFTU applications.

Visualization: The visualization was done using SAS 17 Software, Excel Software 350, and (SPSS 28 Software) program.

4. Results

The chapter aimed to present the revealed results of the examined nutritional properties in the four cereal grains as sorted in the material and methods chapter; the first collection of the research project was focused on evaluating the nutritional properties of the substitute cereal grains, specifically, *S. bicolor* and *P. miliaceum* 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 laboratory measurements were conducted for the whole grains (ground) attributed to diverse varieties samples (appendix 1); 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 stable cereal grain varieties, particularly *S. bicolor* and *P. miliaceum*, and investigate their suitability for human consumption, the approach was conducted by employing a novel procedure of the Husking Fractio Time Unit (HFTU) process. 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 in the whole grains and followed by colour profile assessments for the selected *S. bicolor* and *P. miliaceum* husked products.

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

Certainly, the study was described as attributed to three independent collections were detailed as follows:

4.1. 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. miliaceum* based on the sandy soil, as was shown in (Tables 4 to 8). While the study has promoted the *S. bicolor* and grain varieties by conducting an experiment attributed to soil types based on cultivation site outcomes from Karcag (loam clay) and Nyíregyháza (sandy) under N fertilizer conditions, it consisted of a treatment of 60 kg/ha and 120 kg/ha (Tables). Accordingly, the findings outcomes differences were assessed based on $P \leq 0.05$.

Table 4. 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 x Treatment	9	3005099 ^{NS}	1388880.8 ^{NS}	476603.40 **	271224.0***	1228.9***	1120402.01***
Year x 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

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 macro-mineral in the *S. bicolor* grain attributed to the sandy soil and loam clay soil for 2020 and 2021 production seasons

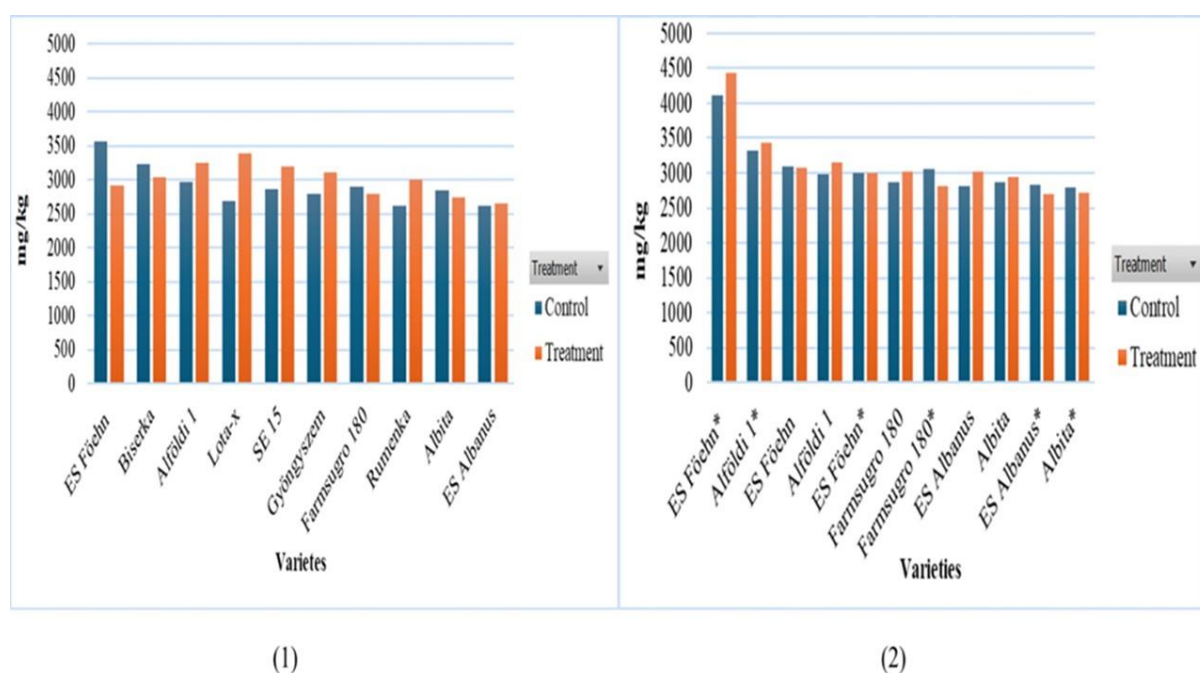
Factor	DF	K	P	S	Mg	Na	Ca
Variety	4	12761506**	216942.7***	231781.64***	302363.64***	3885.26***	231781.64***
Year	1	4400886**	608228.0**	5183332 ^{NS}	1197.49 ^{NS}	458.587 ^{NS}	81916.83***
Treatments	1	6733110.0**	1774920**	47042.8 ^{NS}	429703.37***	1786.588 ^{NS}	2135.7 ^{NS}
Soil type	1	10310975***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

4.1.1. Phosphorus (P)

According to Table 4, the phosphorus mineral showed a significance value of $P < 0.05$, attributed to variety and treatment factors in the case of the sandy soil. In contrast, no significant value $P > 0.05$ was indicated by soil factor (Table 5) in the case of *S. bicolor* grains.

Furthermore, Figure 12 presents the phosphorus (P) mineral variation among all examined varieties. Despite the adverse impact of N fertilizer application among *S. bicolor* varieties, the ES Föehn* variety showed the highest P mg/kg level within 3532.8 mg/kg after applying N fertilizer, confirmed by the essential P mineral level data in the loam clay soil Table 2.



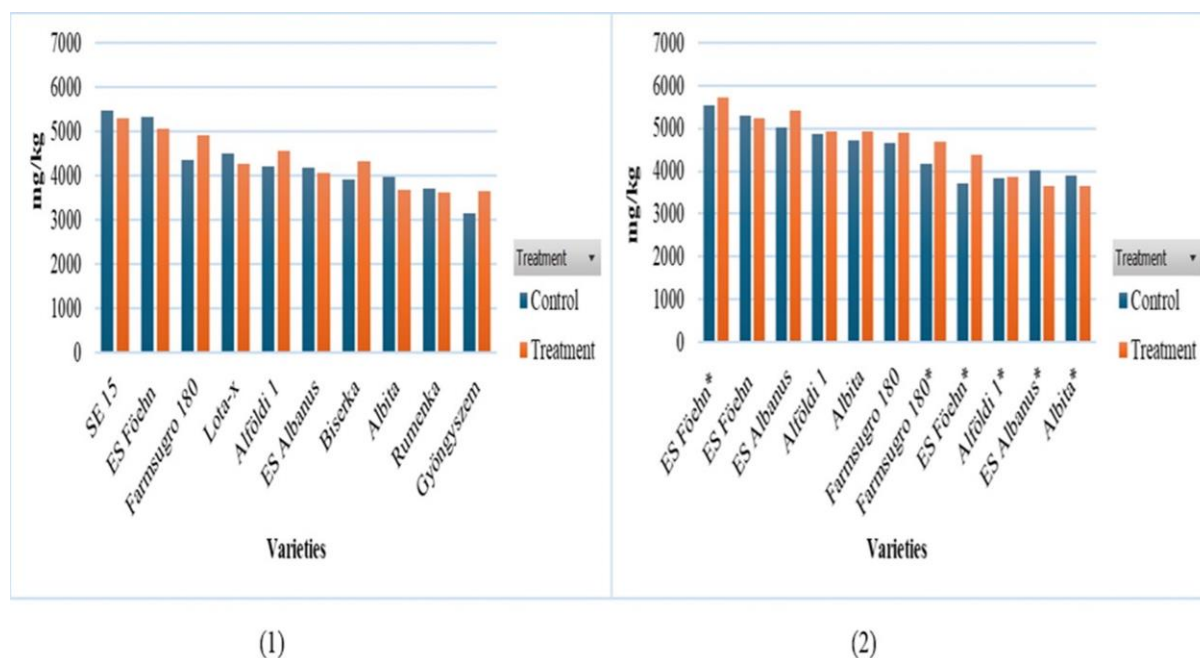
*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 12. Average of phosphorus (P) mineral contents attributed to N fertilizer treatment for 2020 and 2021 cultivation seasons

4.1.2. Potassium (K)

The potassium (K) mineral content of cereal grains did not show a significance value of $P > 0.05$ (Tables 5 and 7). However, in the case of Variety x Treatment interaction, the highest average of K mg/kg was noticed by the SE15 variety (winter wheat) instance of the sandy soil and the ES Föehn variety (benchmark) instance of two different soil types (loam clay and sandy), as shown in Tables 10 and 11. The values demonstrated after N fertilizer application

within. While the most important result was the potassium (K) mineral levels across the various cereal grains, the data also revealed that sorghum grain had negative impacts following N fertilizer application among the diverse varieties originating in sandy soil (Table 4).

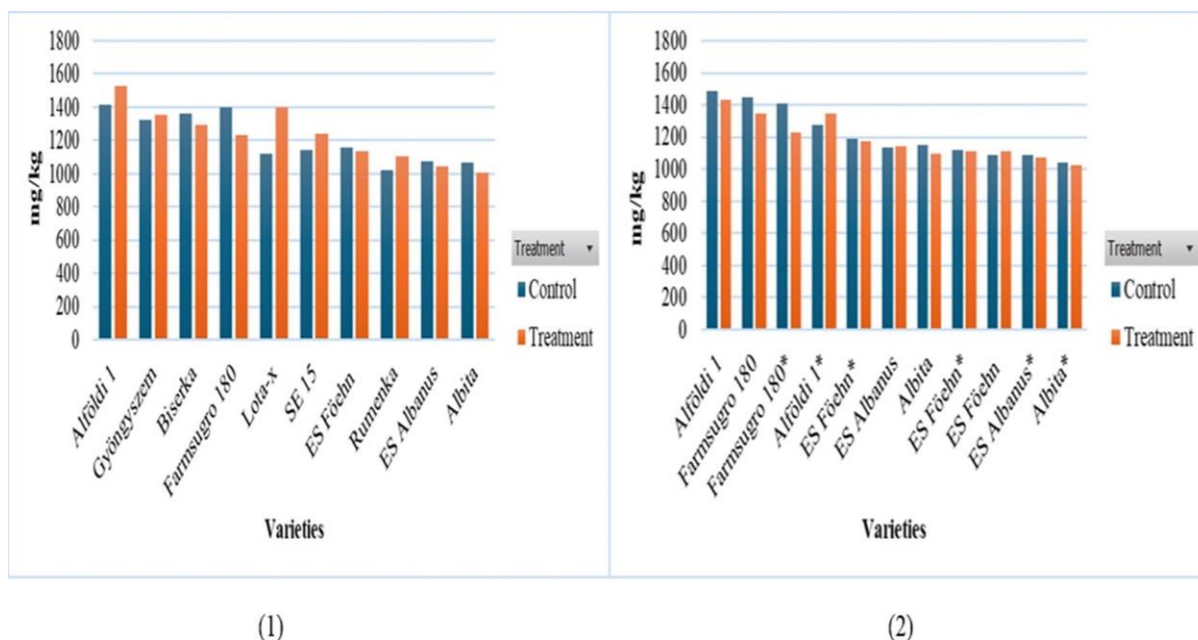


*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 13. Average of potassium (K) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

4.1.3. Sulphur (S)

The results of sulphur (S) mineral contents in the different grain varieties were indicated by a significance value of $P < 0.05$, as presented in Table 4. While the average of S mg/kg has fluctuated among the tested cereal grain varieties; accordingly, the highest average of S mg/kg was indicated by Alföldi 1 (red variety) and Lota variety (oat) from the sandy soil source (Figure 14), as were recorded averages within 1525.6 mg/kg and 1397.5 mg/kg according to observed ranges after N fertilizer application. Moreover, the Variety x Treatment interaction demonstrated a significant variation of ($P < 0.05$), as shown in Table 6.



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

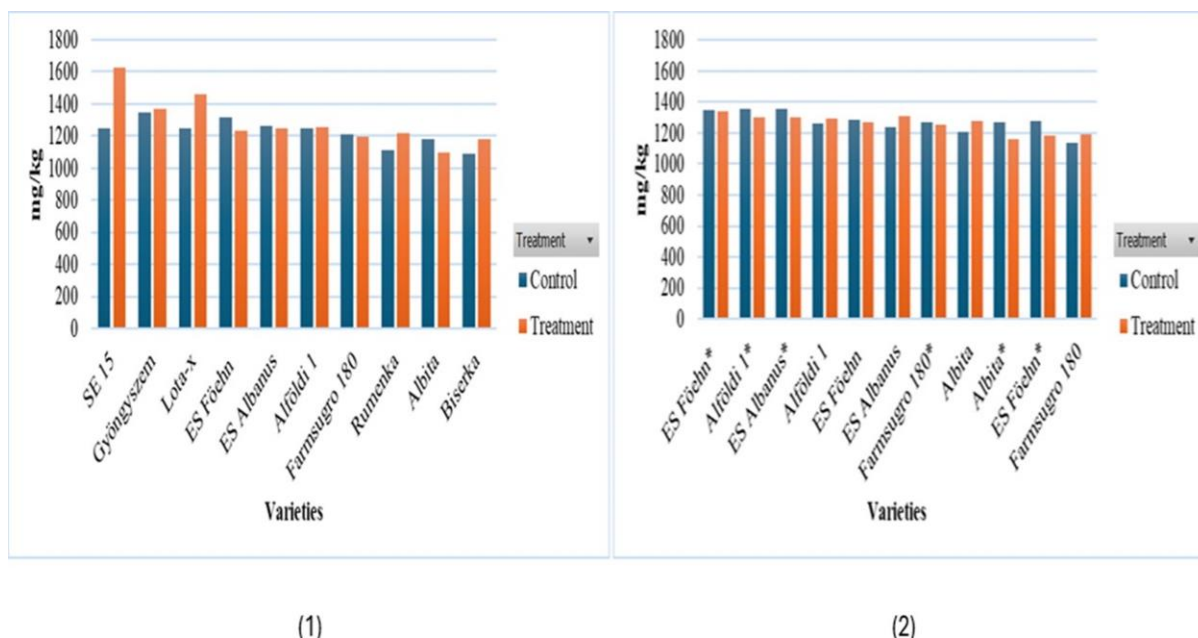
Figure 14. Average of sulphur (S) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

The noticeable result of sulphur (S) mineral can be interpreted by the mentionable adverse impacts of N fertilizer application on the Farmsugro180 variety on the two soil types (sandy and loam clay) based on their control and fertilizer of S mg/kg, which appeared within (1448.4 to 1380.2) mg/kg for the Farmsugro180 variety in sandy soil and (1405.4 to 1215.3) mg/kg. In contrast, the average of 1441.8 mg/kg resulted from the loam clay soil (Table 10).

4.1.4. Magnesium (Mg)

Magnesium (Mg) mineral contents showed a significant difference ($P < 0.05$) attributed to variety and treatment factors of the diverse grain varieties in the sandy soil, as was referred to in Table 4, and sorghum grain varieties in loam clay and sandy soil as are displayed in Tables 7 and 11. The highest average of Mg mg/kg was shown by the Lota variety (oat) within 1733.1 mg/kg, and the lowest average by the Biserka variety (millet) within 1154.4 mg/kg, which was evidenced by a significance value ($P < 0.05$), as was shown in Figure 15.

Despite to high average of Mg mg/kg within 1733.0 mg/kg observed by SE15 (winter wheat) variety and Lota variety (oat) within average of 1623.0 mg/kg and 1461.9 mg/kg (Figure 15). Despite to high average of Mg mg/kg within 1733.0 mg/kg observed by SE15 (winter wheat) variety and Lota variety (oat) within average of 1623.0 mg/kg and 1461.9 mg/kg (Figure 15).



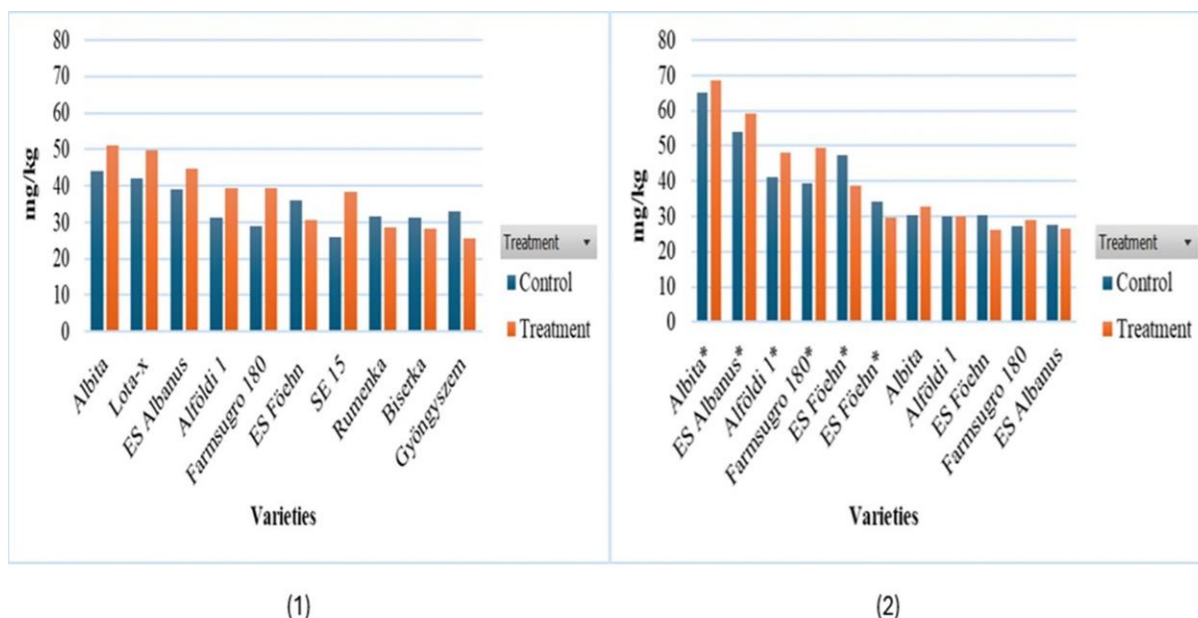
*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 15. Average of magnesium (Mg) mineral contents attributed to sandy soil for the 2020 and 2021 cultivation seasons

On the other hand, the year factor did not show any significant impact, as presented by ($P > 0.05$), according to proven results in Tables 4 and 5.

4.1.5. Sodium (Na)

According to the revealed results of sodium (Na) mineral contents among diverse cereal grains, the treatment factor did not show a significant value ($P < 0.05$) in the case of the sorghum, *P. miliaceum* oat, and winter wheat grain varieties in the sandy soil and diverse sorghum grain varieties in the loam clay and sandy soil, as were shown in Tables 4 and 5. Moreover, the sequenced average of Na mg/kg was demonstrated by the highest average for the Albita variety (sorghum) and Lota variety (oat) from sandy soil sources within 51.2 mg/kg and 49.8 mg/kg (Figure 16). The finding indicated that no significant differences ($P < 0.05$) were attributed to treatment or year factors based on the sandy soil and two soil types (sandy and loam clay) detailed in Tables 4 and 5. In contrast to Variety x Treatment and Year x Treatment, the interactions showed a significant variance of ($P < 0.05$), which resulted in average values detailed in Tables 10 and 11.



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

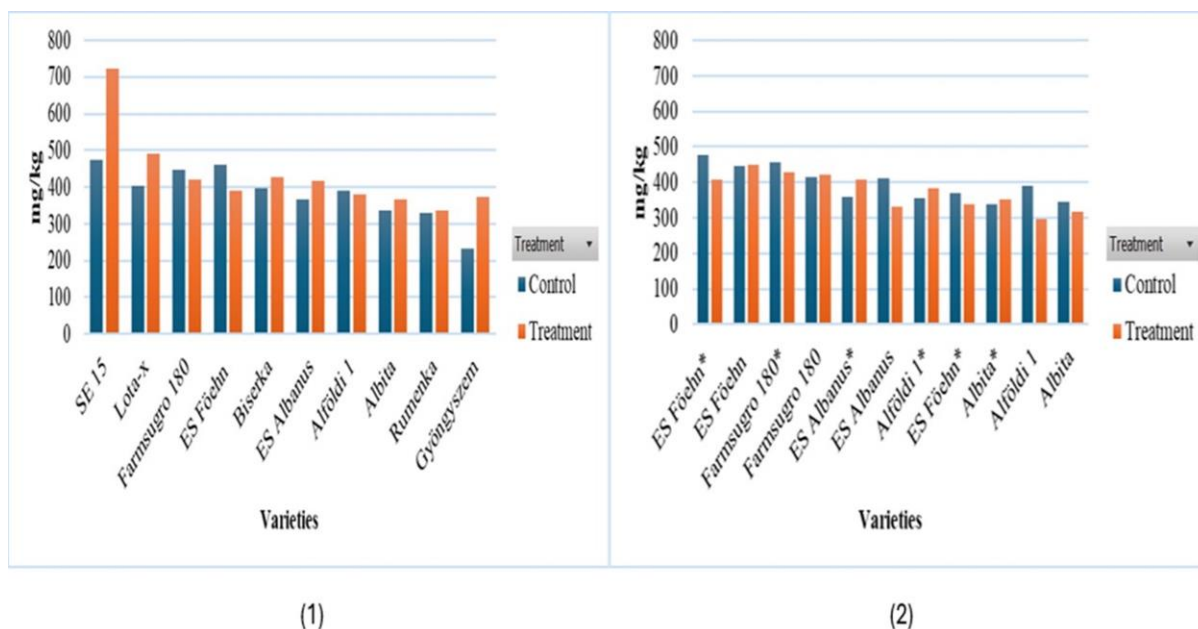
Figure 16. Average of sodium (Na) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

4.1. 6. Calcium (Ca)

The treatment factor demonstrated a fluctuating impact among diverse cereal grains, showing a significance value ($P < 0.05$) based on the sandy soil. In contrast, there was no significance value ($P > 0.05$) in the case of sorghum grain varieties in sandy soil and loam clay, as was demonstrated in (Tables 4 and 5), as well as the highest average was demonstrated by the SE15 variety (winter wheat) and Lota variety (oat) 724.1 mg/kg and 486.6 mg/kg, according to their representation in Figure17.

According to analyzed data in Tables 6 and 7, the Year x Treatment has indicated a significance value of $P < 0.05$ attributed to diverse cereal grains in the sandy soil, which was contrary to no significance value attributed to sorghum grain varieties in the sandy and loam clay soil ($P < 0.05$), where their fluctuated average of Ca mg/kg was explained in Figure 17.

Moreover, the sorghum grain varieties did not present any significant impact, as was interpreted by ($P > 0.05$), as shown in Table 5 and supported by analyzed data in Table 11.



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 17. Average of calcium (Ca) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

Table 6. Statistical analysis of experiment variables of microminerals on diverse cereal grains attributed to the sandy soil for 2020 and 2021 production seasons

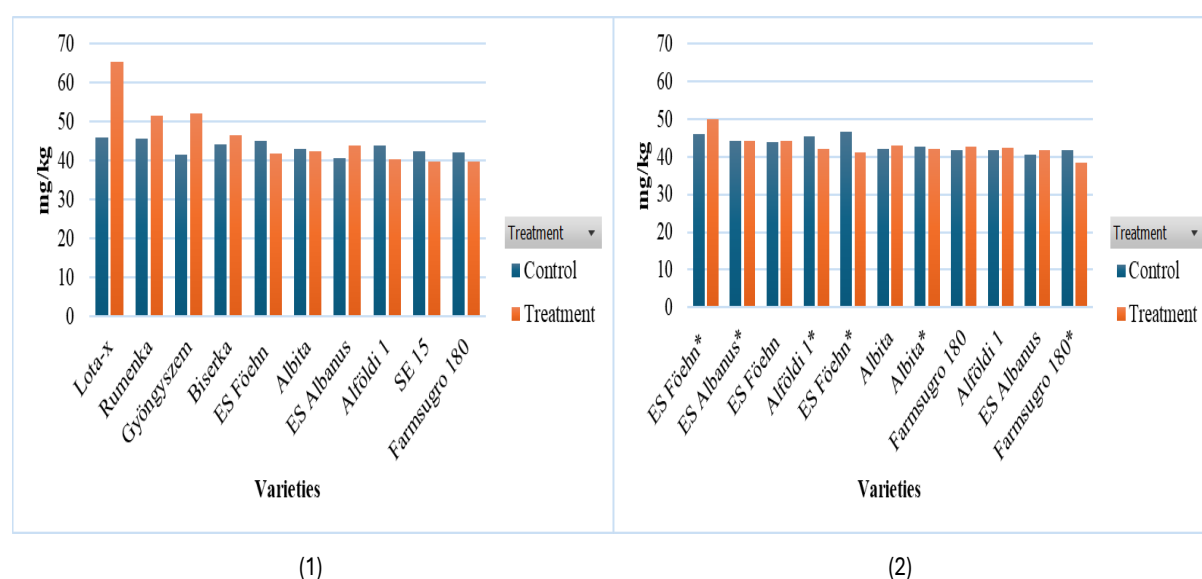
Factor	DF	Fe	Cu	Zn	Mn
Variety	9	3158.73***	11567.86***	193.70***	8488.3***
Year	1	49.077 ^{NS}	0.484 ^{NS}	49.08***	193.861 ^{NS}
Treatment	1	1082.8***	37.1**	60.95***	101.9 ^{NS}
Variety*Year	9	1346.5***	13.52***	549.14**	551.75***
Variety*Treatment	9	1327.8***	25.62***	151.49***	121.9312***

*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

4.1.7. Iron (Fe)

According to analysis outcomes in Tables 6 and 7, the variety and treatment factor demonstrated a significance value ($P < 0.05$). At the same time, soil type indicated a significant difference ($P < 0.05$) attributed to loam clay and sandy soil in the case of sorghum grain varieties (Table 10), as well as a significant variance ($P < 0.05$) attributed to Fe mg/kg accumulation in various grain varieties Gyöngyszem, Rumenka variety (millet), and Lota variety (oat), by demonstrated ranges within 65.2 mg/kg, 51.9 mg/kg, and 51.5 mg/kg, respectively (Figure 18).

Fe mg/kg findings did not indicate any significant variance ($P > 0.05$) attributed to Variety $\times$ Year, Treatment $\times$ Year, Variety $\times$ Soil types, as shown in Table 9. However, the variety factor noticed a significant value of ($P < 0.05$), as shown in Table 7.



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 18. Average of iron (Fe) mineral contents attributed to N fertilizer treatment for 2020 and 2021 cultivation seasons

Table 7. 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**

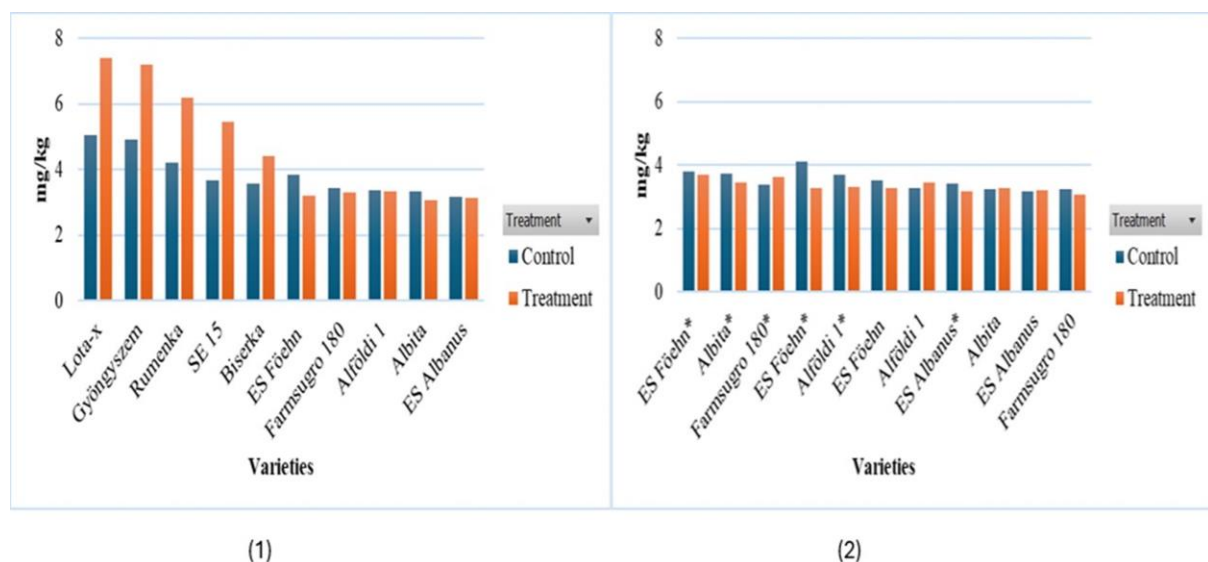
Treatments	1	341.8363***	1.594015 ^{NS}	107.5333***	4.8372142 ^{NS}
Soil type	1	155.81064**	5.877845***	58.10965***	11.506477**
Variety× Year	4	84.19092 ^{NS}	1.2145947 ^{NS}	33.19503 ^{NS}	4.049608**
Variety × Treatment	4	198.0003 ^{NS}	1.739524 ^{NS}	41.4461 ^{NS}	6.9483814 ^{NS}
Variety × Soil type	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

4.1.8. Copper (Cu)

The findings of copper (Cu) mineral were varied and attributed to diverse cereal grains of winter wheat, oat, *S. bicolor*, and *P. miliaceum* compared to sorghum grain varieties belonging to two soil types (sandy soil and loam clay), where the analysis outcomes showed a similar result of Year x Treatment interaction ($P < 0.05$), as was demonstrated in Tables 6 and 7.

The results showed that oat and *P. miliaceum* varieties (Figure 19) had the highest Cu mg/kg contents compared to winter wheat and sorghum grain varieties.



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

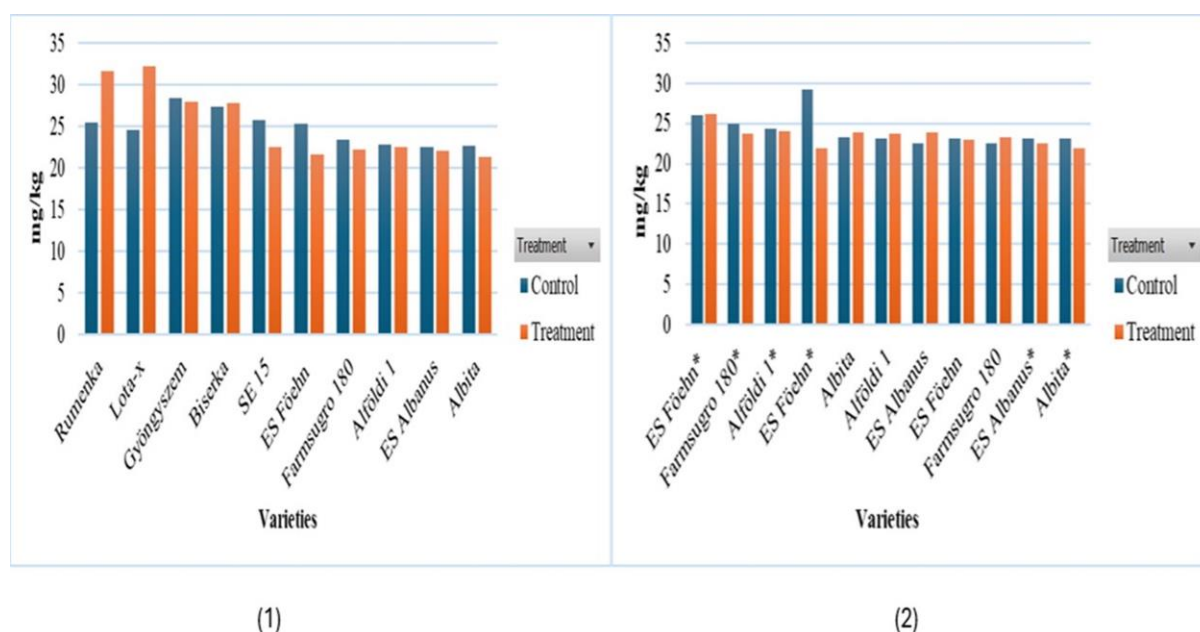
Figure 19. Average of copper (Cu) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

4.1.9. Zinc (Zn)

As evidence for the analysis measurement outcomes, the variance of the variety factor was indicated by a significance value of $P < 0.05$ in the case of diverse cereal grains on the sandy soil (Table 6); in contrast, the variety factor did not show a significance difference ($P > 0.05$), attributed to *S. bicolor* varieties as was shown in Table 7.

On the other hand, the N fertilizer indicated a notable adverse impact on Zn mg/kg content on the SE15 variety (winter wheat) and ES Föehn* variety (*S. bicolor*) from the clay soil site, as detailed in Figure 20 and Table 10. In comparison, the highest average of Zn mg/kg was recorded by the Rumenka variety (*P. miliaceum*) and Lota variety (oat) within 31.5 mg/kg and 32.2 mg/kg, with a significance value of ($P < 0.05$), as detailed in Figure 20. As well as an instance of Variety x Soil type ($P > 0.05$).

As mentioned, the Zn mg/kg contents were similar to Cu mg/kg. The highest concentration of Zn mg/kg was observed among *P. miliaceum* varieties, as explained in Figures 19 and 20.

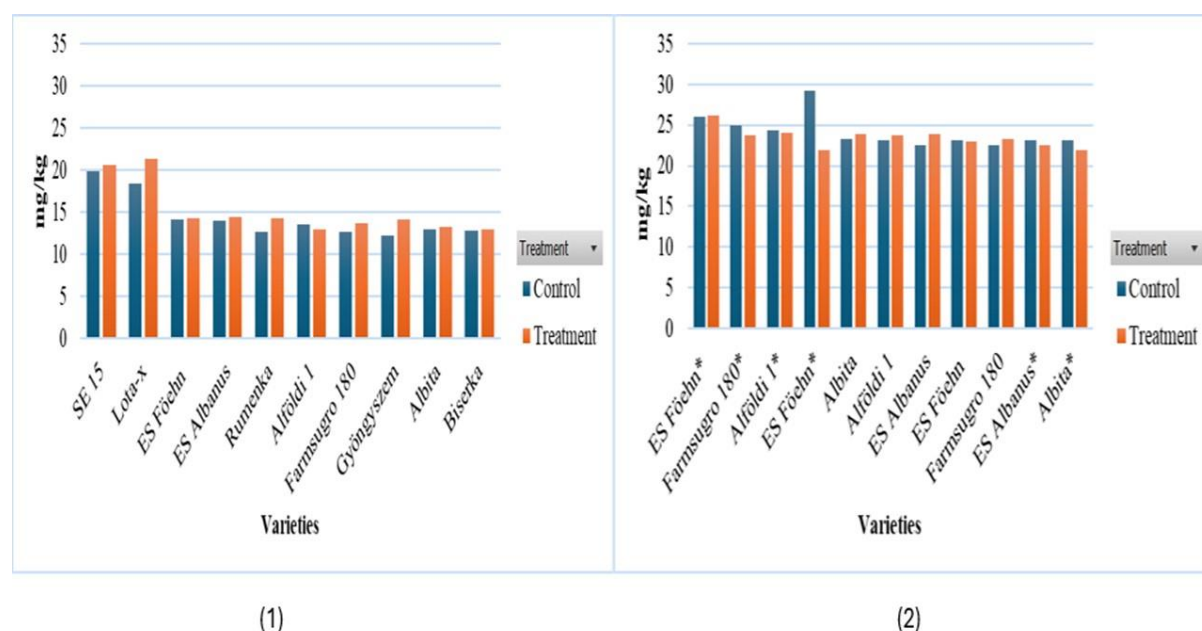


*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 20. Average of zinc (Zn) mineral contents attributed to sandy soil for 2020 and 2021 cultivation seasons

4.1.10. Manganese (Mn)

The revealed result of the manganese (Mn) mineral did not show a significant value ($P < 0.05$) among all the measured cereal grains in Tables 4 and 6. In contrast, a significance value ($P < 0.05$) was indicated by the soil type factor (Table 6) in the case of sorghum varieties in the sandy soil (Table 11). Despite the adverse effect of N fertilizer application, the Mn mg/kg content did not show a significance value ($P > 0.05$) belonging to the treatment factor (Table 6).



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 21. Average of manganese (Mn) mineral contents attributed to sandy soil for the 2020 and 2021 cultivation seasons

4.1.11. Crude protein

According to the revealed findings of the crude protein in all examined cereal grains cultivated in the sandy soil which indicated that is the variety factor showed a significance value of $P < 0.05$ (Table 8), as well as; similar finding was recorded by variety and soil type factors, which attributed to *S. bicolor* instance of the two soil (sandy and loam clay) and showed a significance value of ($P < 0.05$), according to sorghum analysis outcomes (Table 9).

Supported the effective impact of the variety factor when the highest calculated average was demonstrated by the SE15 variety (winter wheat) within 20.3 g/kg after N fertilizer application. In contrast, the Albita variety (sorghum) showed a lower N g/kg among the two independent experiments instances of the sandy soil (diverse cereal grains) and the case of the two soil types (sandy and loam clay) based on presented average in Tables 10 and 11 within the range of (11.5 to 10.4) g/kg after N fertilizer treatment, according to presented average values in (Figure 22). Despite the similar range of crude protein observed by diverse measured cereal grains such as oat, *P. miliaceum*, and *S. bicolor* grain varieties, as explained in (Figure 19), *P. miliaceum* varieties were revealed with abundant crude protein levels, ranging from (18.5 to 17.6) g/kg; findings were aligned with the research investigation by (Karkannavar et al., 2021), the study proved that the *P. miliaceum* grain has high total protein (N) levels.

Table 8. Statistical analysis of experiment variables of crude protein (N) contents on diverse cereal grains attributed to the sandy soil for 2020 and 2021 production seasons

Factor	DF	MS
Variety	9	1084.0***
Year	1	31.4 ^{NS}
Treatment	1	0.619 ^{NS}
Variety × Treatment	9	64.794 ^{NS}
Year × Treatment	1	10.79 ^{NS}

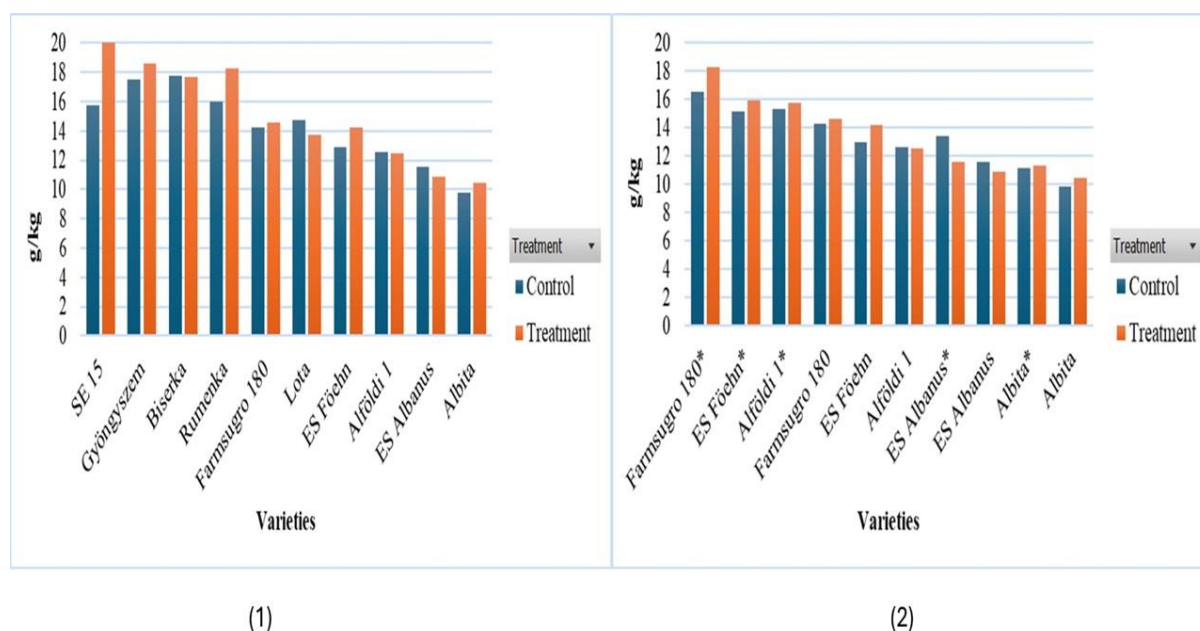
*Denotes differences that are statistically significant. All results are based on a dry basis of two reading replications, attributed *** for $P < 0.001$, NS for no significance value

According to Tables 8 and 9, the statistical findings indicated that the variety factor was sufficient in the agricultural practice of the two experiments of the diverse cereal grains and sorghum grains, which showed a significant value of $P < 0.05$. In comparison to other measured factors such as treatment, despite to increasing of the crude protein among all experienced cereal grains after N fertilizer application, the statistical analysis of the treatment factor did not show a significant variance $P < 0.05$.

Table 9. Statistical analysis of experiment variables of crude protein (N) contents on *S. bicolor* grains attributed to the sandy soil and loam clay soil for 2020 and 2021 production seasons

Variables	DF	MS
Variety	4	439.59141 ^{***}
Year	1	9.76411 ^{NS}
Treatment	1	61.66462 ^{NS}
Soil type	1	143.6422 ^{***}
Variety× Treatment	4	38.07854 ^{NS}
Year× Treatment	1	1.955355 ^{NS}

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



*Star mark refers to varieties from the loam clay soil, values demonstrated based on three reading replications, values based on mean $\pm$ SD, $P \leq 0.05$.

Figure 22. Average of crude protein (N) mineral contents attributed to sandy soil for the 2020 and 2021 cultivation seasons

Table 10. Statistical analysis of the essential nutritional content profiles for the *S. bicolor* grain crop after the application of N fertilizer in the loam clay soil

Variables	N g/kg ⁻¹	P mg/kg ⁻¹	K mg/kg ⁻¹	S mg/kg ⁻¹	Ca mg/kg ⁻¹	Mg mg/kg ⁻¹	Fe mg/kg ⁻¹	Zn mg/kg ⁻¹	Cu mg/kg ⁻¹	Na mg/kg ⁻¹	Mn mg/kg ⁻¹
Standard	15.8±1.8	3257.85±415.1	1166.66±71.6	430.56±97.2	5211.13±901.8	1079.81±567.5	49.17±3.6	32.97±1.5	27.11±2.0	3.98±0.3	14.35±0.7
Alföldi 1	16.5±1.7	3200.20±302.7	1225.75±188.4	397.72±107.7	4861.37±921.8	1361.34±82.6	41.39±5.8	38.45±1.3	24.77±1.2	3.91±0.5	14.13±0.7
ES Albanus	12.3±1.4	2840.55±232.0	1079.21±30.2	313.85±75.6	3967.68±732.8	1357.94±251.1	43.71±2.0	53.32±4.9	23.08±0.4	3.40±0.2	14.70±0.6
Albita	11.9±1.9	2868.96±159.3	1056.77±56.6	297.25±83.3	3911.27±573.8	1281.50±68.6	44.53±2.0	56.76±11.3	23.61±0.7	3.49±0.8	13.35±0.7
Farmsugro 180	18.7±2.4	3065.99±167.0	1441.89±351.0	470.15±39.6	4695.81±1089.7	1265.22±92.4	42.90±1.2	42.46±6.1	24.83±7.3	3.40±0.2	12.65±1.2
P-value	<.001	0.05	<.001	0.03	0.04	0.03	0.33	0.04	0.02	0.65	0.17

#N element content was analyzed separately in comparing the difference due to different content values, calculated from two replication readings per g/kg, while the averages of mineral contents among different sorghum grain varieties were calculated from three replication readings, all nutrients were on the dry basis (P < 0.05)

Table 11. Statistical analysis of the essential nutritional content profiles for the *S. bicolor* grain crop after the application of N fertilizer in the sandy soil

Variables	N g/kg ⁻¹	P mg/kg ⁻¹	K mg/kg ⁻¹	S mg/kg ⁻¹	Ca mg/kg ⁻¹	Mg mg/kg ⁻¹	Fe mg/kg ⁻¹	Zn mg/kg ⁻¹	Cu mg/kg ⁻¹	Na mg/kg ⁻¹	Mn mg/kg ⁻¹
Standard	15.3±1.7	3104.81±109.3	5199.60±362.8	1061.83±69.7	454.05±28.0	1339.15±104.2	46.26±3.2	22.97±1.1	3.38±0.1	26.97±4.3	14.79±0.9
Alföldi 1	13.8±1.7	3157.75±302.0	4552.84±92.8	1334.00±116.5	386.48±49.7	1290.57±100.6	41.70±1.8	24.26±1.3	3.38±0.0	21.75±4.9	13.88±0.6
ES Albanus	11.2±1.4	2930.98±300.5	5102.5±200.9	1168.28±99.2	416.26±73.1	1284.01±84.9	41.46±2.4	23.04±1.7	3.13±0.1	27.98±1.9	14.81±0.8
Albita	10.4±1.9	2925.06±240.5	4790.62±101.1	1173.18±130.7	326.76±65.5	1263.96±97.8	42.61±2.3	23.94±1.3	3.29±0.1	30.42±2.1	13.51±0.2
Farmsugro 180	15.7±2.4	3090.79±202.7	4990±405.0	1442.58±158.5	438.30±51.4	1153.23±60.7	42.95±1.7	23.49±9.0	3.03±0.1	27.1±4.5	13.35±0.2
P-value	<.001	0.04	0.39	<.001	0.71	0.49	0.67	0.43	0.7	0.55	0.002

#N element content was analyzed separately in comparing the difference due to different content values, calculated from two replication readings per g/kg, while the averages of mineral contents among different sorghum grain varieties were calculated from three replication readings, all nutrients were on the dry basis (P < 0.05)

4.1.12. Principal component analysis (PCA)

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 23) 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 mineral showed 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.

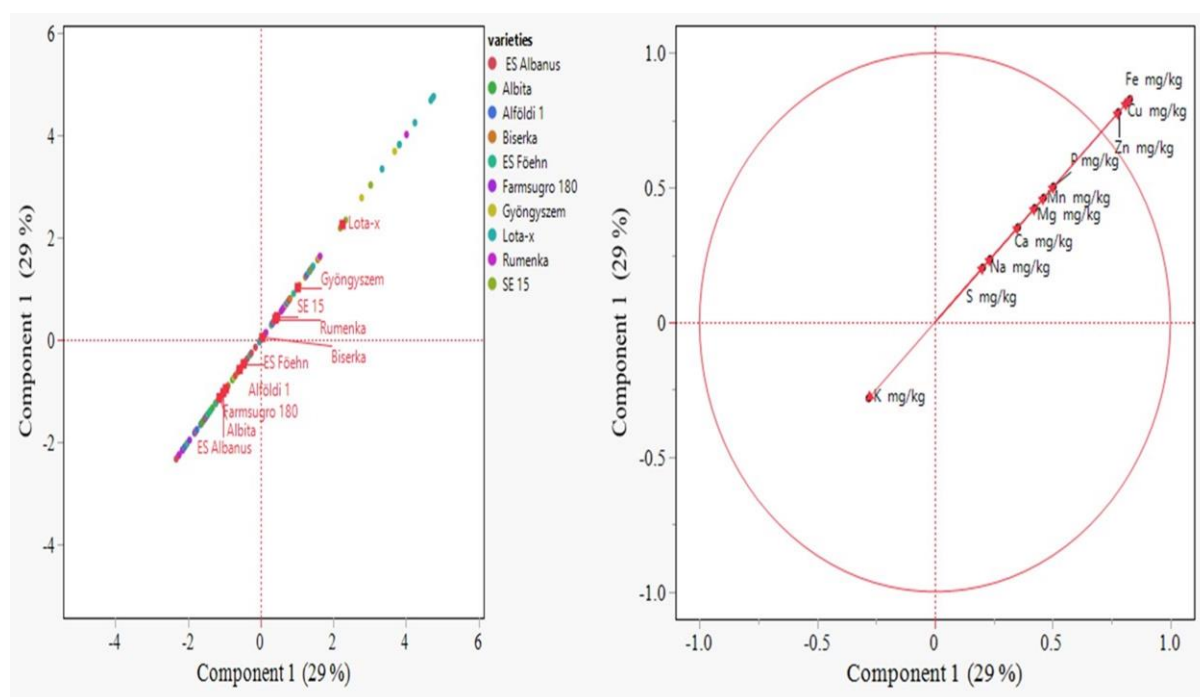


Figure 23. The principal component analysis of diverse cereal grain under N fertilizer sandy soil conditions, $P \leq 0.05$

4.1.13. Mineral profile variation implied from the sandy soil conditions

According to the second research project collection, as detailed in (Appendix 1), the elemental nutrients were evaluated independently and attributed to respective crops. The finding revealed fluctuating mineral contents among the diverse cereal grains; for instance, the N g/kg was sequenced as follows: winter wheat > *S. bicolor* > oats > *P. miliaceum*, as was detailed in Table 10. Furthermore, we can estimate the accuracy of the finding outcomes by the accumulation of Fe mg/kg and Zn mg/kg on the respective cereal grains when both minerals indicated the same reading concentration as was observed by the highest level in winter wheat > *P. miliaceum* > *S. bicolor* > oat, according to (Table 10).

Table 12. Descriptive statistics of the elemental composition variations among alternative cereal grains attributed to sandy soil conditions for 2020 and 2021

Variables	Proso millet					Sorghum				
Statistical test	N	Mean	Std. Deviation	Minimum	Maximum	N	Mean	Std. Deviation	Minimum	Maximum
N g/kg	18	17.6	0.5	17.1	18.0	29	12.4	1.7	10.1	14.4
P mg/kg	36	2961.2	449.9	2015.6	3860.2	59	2919.9	508.5	2326.1	4916.3
K mg/kg	36	3731.9	1088.9	2046.1	5837.9	59	4448.4	879.7	3075.4	6127.8
S mg/kg	36	1242.7	232.8	920.5	1792.8	59	1205.4	238.9	901.1	1907.7
Ca mg/kg	36	349.4	122.9	101.5	568	59	398.8	95.7	201.9	673.0
Mg mg/kg	36	1219.3	151.9	1000.7	1514.8	59	1234	135.3	1004.0	1494.5
Na mg/kg	36	29.8	6.4	19.4	44.4	59	38.0	17.9	20.9	102.4
Cu mg/kg	36	5.1	1.6	2.1	7.9	59	3.2	0.5	2.06	5.3
Fe mg/kg	36	46.8	6.5	38.2	62.8	59	42.4	4.9	23.5	53.0
Zn mg/kg	36	28.1	5.6	22.0	36.1	59	22.6	2.1	19.5	29.4
Mn mg/kg	36	13.2	1.2	10.1	15.5	59	13.6	0.9	11.1	15.6

*Values presented statistic outcomes-based values of (control (without N fertilizer) and treated (with N fertilizer))

Table 13. Descriptive statistics of the elemental composition variations among staple cereal grains attributed to sandy soil conditions for 2020 and 2021

Variables	Winter wheat					Oat				
Statistical test	N	Mean	Std. Deviation	Minimum	Maximum	N	Mean	Std. Deviation	Minimum	Maximum
N g/kg	6	18.7	2.4	20.3	16.8	6	14.3	2.9	12.1	16.3
P mg/kg	12	3345.6	397.8	2582.4	4012	12	3005.6	209.2	2671.4	3214.9
K mg/kg	12	4226.6	587.8	3333.9	5407.8	12	5605.8	924.1	3789.1	6716.6
S mg/kg	12	1349.1	150.3	1066.5	1518.8	12	1132.8	88.5	1003.5	1230.6
Ca mg/kg	12	754.6	257.2	443.1	1118.5	12	627.2	173.9	430.0	895.8
Mg mg/kg	12	1172.9	84.9	1032.1	1289.9	12	1548.5	222.2	1246.7	1825.7
Na mg/kg	12	28.5	9.3	16.5	42.2	12	31.1	10.7	21.8	48.4
Cu mg/kg	12	4.8	1.4	3.5	8.5	12	4.4	1.3	3.1	6.3
Fe mg/kg	12	49.4	13.7	34.3	71.5	12	40.5	4.3	35.3	49.9
Zn mg/kg	12	29.2	3.7	23.9	33.9	12	21.3	1.4	19.0	24.2
Mn mg/kg	12	41.9	7.5	34.9	53.3	12	17.4	7.5	12.2	32.3

4.2. 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 *P. miliaceum* dehulling process set times 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 14 to 17 with the variations in nutritional mineral profiles, as depicted in Figures 24 to 27.

We conducted a precision evaluation of the husking process by comparing the percentage of the obtained bran fraction to the waste (g) amount, as presented in (Tables 14 to 17), demonstrating the HFTU process's implications on the two milling fractions. The following details explain all relevant results independently.

4.2.1. Results of the Husking Fraction Time Unit (HFTU) technique based on the variety and regions

4.2.1.1. Commercial sorghum grain varieties

Macro-mineral

Protein: The redistribution and concentration of proteins in the grain architecture played a crucial role in ensuring the precision of the dehulling process. Particularly, that attributed to diverse time units as resulted from the HFTU technique, when the Farmsugro180 variety showed the highest level of crude protein levels implied from the 30s and 80s with an average

of 17.5 g/kg and 16.3 g/kg. In contrast, the crude protein average fluctuated among other varieties, as demonstrated in Figure 24 [1-2], with a significance variance of $P < 0.05$. Although there were differences in the redistribution of variation among the different varieties, the results of the analysis showed that the varieties obtained from Hortobágy had a high resistance to the dehulling process, as indicated by the recorded average crude protein levels in Figure 24 [1-2]. Contrary to the crude protein result of the E7 variety, the H7 variety showed a higher percentage of bran fraction in the applied husking process (Table 14). Specifically, the presented data indicated that the bran fraction result for the H7 variety was between 27.6% and 31.5%, with the 30s and 80s accounting for the higher percentages. This result contrasted with the averages in Figure 24 [1-2].

Table 14. Result of the applied husking procedure on the commercial sorghum grain varieties

		30 sec					80 sec				
Samples	weight (g)	Bran (g)	Bran (%)	Endosperm (g)	Endosperm (%)	Waste (g)	Bran (g)	Bran (%)	Endosperm (g)	Endosperm (%)	Waste (g)
H4	50	6.95	13.90	34.85	69.71	8.21	12.45	24.91	29.52	59.04	8.03
H1	50	6.75	13.50	35.45	70.90	7.82	12.78	25.56	28.35	56.71	8.87
H7	50	9.85	19.70	30.50	61.00	9.65	18.95	37.90	19.35	38.72	11.50
Ny4	50	5.82	11.64	39.02	78.40	4.83	9.25	18.52	35.48	70.96	5.25
Ny1	50	5.15	10.30	37.68	75.36	7.20	10.13	20.26	33.78	67.56	6.09
Ny7	50	5.28	10.56	36.75	73.50	7.90	9.31	18.62	32.15	64.34	8.54
E4	50	7.68	15.36	36.43	72.86	5.91	14.22	28.44	29.01	58.02	6.77
E1	50	10.00	20.00	33.91	67.82	6.11	16.43	32.86	24.78	49.56	8.79
E7	50	13.83	27.66	35.45	70.90	0.72	15.78	31.56	24.08	48.16	7.14
K180	50	38.26	76.52	5.33	10.66	6.41	30.54	61.08	16.34	32.68	3.12
K 1/4	50	37.47	74.94	7.03	14.06	5.50	30.56	61.12	16.68	33.36	2.76
Ny 180	50	44.15	88.29	1.33	2.67	4.52	32.5	65.00	4.35	8.70	13.15
Ny 1/4	50	37.45	74.91	5.90	11.80	6.65	35.09	70.18	10.63	21.27	4.27

Phosphorus: The peeling results for P mg/kg contents were compared to the P mg/kg levels found in different varieties. These levels were determined based on utilized of 30s- and 80s-time units. Among the same varieties sourced from three regions, the E1 variety had the highest bran percentage at 27.6% when measured at 30s. The E1 variety, which served as the benchmark seed, had a bran percentage of 28.4% when measured at 80 (S) during the peeling process, as shown in Figure 24 (1-2). The significance value was $P < 0.05$. The ES Föehn (benchmark seed) from three locations (Ny1, H1, and E1) had the highest P mg/kg concentration after 80s-time units, with averages of 7045.9 mg/kg, 6565.9 mg/kg, and 5691.5 mg/kg, respectively.

Potassium: The K mg/kg contents showed fluctuated levels among diverse varieties sourced from various locations, as we noticed that ES Föehn (benchmark seed) from Nyíregyháza and Hortobágy had demonstrated an abundant K mg/kg contents were implied from 80s time unit (Figure 24 (1-2)), with a significance value of ($P < 0.05$), on the other hand, the lowest level of 2696.9 mg/kg and 2659.5 mg/kg were indicated by 180 Ny and 1/4K varieties, as shown in Figure 24 (1-2), contrary to peeling findings in (Table 14), referring to the implied increasing in K mg/kg concentration from 80s time unit.

Sulphur: The ES Foehn variety from Nyíregyháza and Hortobágy had the highest average of S mg/kg, averaging 1851.3 mg/kg and 1456.5 mg/kg, respectively. The 180 Ny variety had an average S mg/kg of 1355.7 mg/kg from the 30s and 2350.1 mg/kg from the 80s. The 1/4Ny, 180K and Ny1 varieties had averages of S mg/kg of 1628.3 mg/kg, 1527.8 mg/kg, and 1476.9 mg/kg, respectively. These results line up with the peeling result in Table 14 and the S mg/kg contents in Figure 24(1-2), showing significant differences ($P < 0.05$). The alfodi1 variety from Nyíregyháza and Hortobágy averaged 770.5 mg/kg from the 30s and 1019.2 mg/kg from the 80s, respectively.

Magnesium: The dehulling process significantly impacted the Mg mg/kg concentration among different varieties (Figure 24 (1-2)). The 180Ny variety and H1 variety showed high Mg mg/kg contents, ranging from 1610.9 mg/kg to 5659.2 mg/kg and 3265.4 mg/kg to 3332.1 mg/kg, respectively, as indicated by the values of 30s and 80s. The revealed variation was statistically significant, with a $P < 0.05$. The obtained findings did not demonstrate any associations between the peeling outcomes, as shown in (Table 14) and the amounts of Mg mg/kg depicted in Figure 24 (1-2). Furthermore, differences between the 30s and the 80s were reported to be 29.9%.

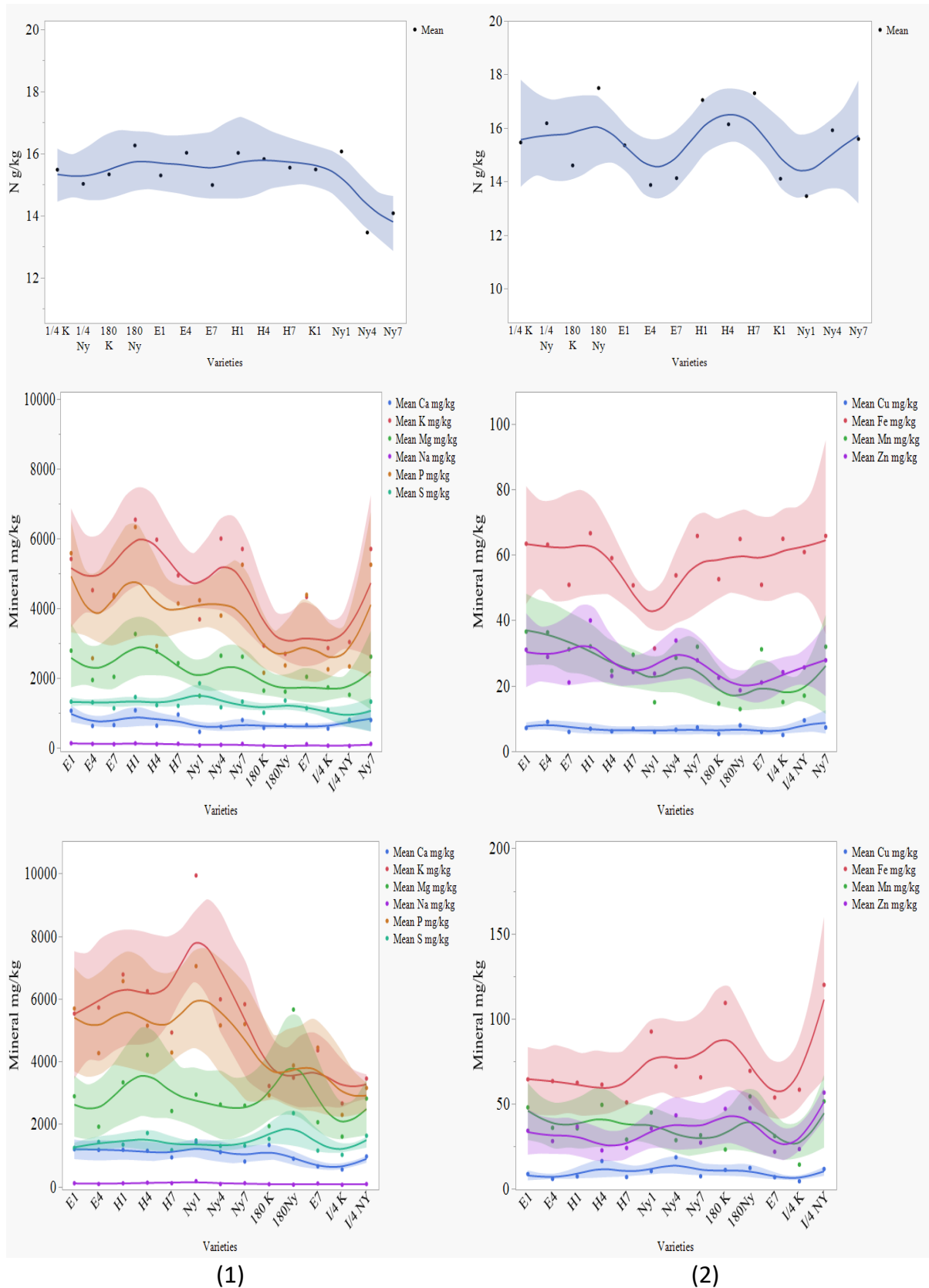


Figure 24. The average of mineral component analysis of diverse *S. bicolor* varieties attributed to diverse varieties and regions, referring to (1) the 30s and (2) the 80s time units, $P \leq 0.05$

Sodium: The most noticeable variation in sodium content was observed in the Alföldi 1 and Farmsugro180 varieties sourced from Kacarg and Nyíregyháza. These varieties demonstrated the lowest sodium levels, as shown in Figure 24 (1-2). This is contrary to the results obtained from peeling, as indicated in Table 16. In the case of the 30s, the sodium levels ranged from 60.5 to 34.6 mg/kg; in the case of the 80s, the range ranged from 85.0 to 60.3 mg/kg. The variation in sodium content within these cases was 13.1%, which resulted from the employed 30s- and 80s-time units.

Microminerals:

Iron: The iron mineral varied across the investigated varieties, but the Fe mg/kg contents closely matched the peeling findings (Table 14). The 1/4N variety had the largest range, with 64.9 mg/kg for 30s and 119.9 mg/kg for 80s. H7 exhibited a consistent range of 50.6 to 50.9 mg/kg, as seen in the 30s and 80s samples, with a variation of 26.3%.

Zinc: The H1 variety exhibited the highest concentration of Zn at 30s. In contrast, the results for Zn concentration at the 80s shown in Figure 24 (1-2) closely matched the peeling result (Table 12), ranging from 56.7 to 47.1 mg/kg. The three regions' ES Foehn variety (benchmark variety) also showed a comparable outcome ($P < 0.05$). The E7 variety from three areas also had an average Zn concentration of 21.0 and 21.9 attributed to 30s and 80s, respectively.

Copper: The concentration of copper minerals indicated varied levels among the different varieties. Figure 24(1-2) shows that the varieties obtained from Nyíregyháza had the highest average Zn mg/kg content. When comparing the average Zn mg/kg contents in Figure 24 (1-2) with the peeling result in Table 14, the variance between the 30s- and 80s-time units was found to be 45.6%.

Manganese: The analysis of Mn mg/kg contents revealed that the sorghum varieties from Esztár had the highest average Mn mg/kg levels, ranging from 31.1 mg/kg to 36.5 mg/kg, resulting from the 30s-time unit, which was noticed as the highest concentration. The 180 variety recorded the highest Mn mg/kg contents and 1/4 variety from Nyíregyháza, with 54.4 mg/kg levels and 51.5 mg/kg, respectively. The K180 and K1/4 varieties had the lowest Mn mg/kg amounts, with average values of 23.2 mg/kg and 14.4 mg/kg, respectively.

4.2.1.2. *Sorghum* grain varieties inbred line

Macro-mineral:

Protein: The crude protein g/kg content findings showed a significant difference ($P < 0.05$) between the 30s and the 80s-time units. Figures 25 (1,2) and 26 (1,2) display the range of crude protein levels in the Kafir race, which is 4.6 to 17.5 g/kg for 30s and 8.8 to 19.2 g/kg for 80 (S). which showed a statistical variance ($P < 0.05$) in the protein levels. Figure 25 shows the crude protein contents and the varied peeling results in Table 15. These show that the bran percentage for the 30s and the 80s-time units is 6.9% and 18.6%, respectively. That varied from the 25.7% seen for the 80s in the *S. bicolor* race (Appendix 15 and 16). The variation in bran percentage is 8.5% across the 30s and the 80s-time units.

Phosphorus: The results showed that the Kafir race had the lowest average of P mg/kg (Figure 25 (1-2)) with an average of 4723.5 mg/kg, compared to the relevant average of 5204.7 mg/kg observed in the *S. bicolor* race Figure 25 (1,2). This difference was statistically significant, with a significance value of $P < 0.05$. The average bran (g/kg) values in Tables 19 and 20 were consistent with these findings. The Kafir race had the lowest average of 3.4 g implied from the bran, while the *S. bicolor* race had an average of 5.2 g at the same time unit of 30s. However, the evaluation revealed that the 80s time unit substantially influenced the P mg/kg content in the *S. bicolor* and Kafir races Figures 25 (1,2) and 26 (1,2). The lowest recorded values were 18481.9 mg/kg and 3420.5 mg/kg.

Potassium: The highest average recorded for the K mg/kg results was 9865.2 mg/kg for the *S. bicolor* race and 11021.8 mg/kg for the Kafir race, with a sample size of 30s. Additionally, there was an increasing average of 11121.9 mg/kg and 12294.2 mg/kg for a sample size of 80s, as shown in Figures 25 (1,2) and 26 (1,2). The significance value of $P < 0.05$. The fluctuation range was found to be quite distinct from the range of the peeling results in Tables 15 and 16.

Table 15. Result of the applied husking procedure on the *S. bicolor* race inbred line

		30 sec					80 sec				
Samples	weight (g)	Endosperm (g)	Endosperm (%)	Bran (g)	Bran (%)	Waste (g)	Endosperm (g)	Endosperm (%)	Bran (g)	Bran (%)	Waste (g)
Alpha1	50	38.38	76.76	6.41	12.82	5.21	31.29	62.58	15.40	30.80	3.31
Alpha 2	50	39.72	79.44	3.45	6.90	6.83	38.81	77.62	8.76	17.52	2.43
Alpha 3	50	38.08	76.16	5.92	11.84	6.00	34.08	68.16	14.13	28.26	1.79
Alpha 4	50	38.30	76.60	5.78	11.56	5.92	33.00	66.00	15.51	31.02	1.49
Alpha 5	50	38.51	77.02	7.36	14.72	4.13	32.85	65.70	16.12	32.24	1.03
Alpha 6	50	38.08	76.16	5.31	10.62	6.61	32.84	65.68	13.33	26.66	3.83
Alpha 7	50	39.45	78.90	3.82	7.64	6.73	35.92	71.84	10.85	21.7	3.23
Alpha 8	50	39.87	79.74	4.50	9.00	5.63	37.01	74.02	11.63	23.26	1.36
Alpha 9	50	39.48	78.96	5.58	11.16	4.94	37.16	74.32	11.26	22.52	1.58
Alpha 10	50	38.03	76.06	5.90	11.80	6.07	33.23	66.46	14.91	29.82	1.86
Alpha 11	50	38.9	77.80	5.80	11.60	5.30	35.09	70.18	13.15	26.3	1.76
Alpha12	50	39.35	78.70	2.67	5.34	7.98	36.53	73.06	7.82	15.64	5.65
Alpha13	50	39.28	78.56	3.93	7.86	6.79	36.49	72.98	10.43	20.86	3.08
Alpha14	50	39.92	79.84	2.67	5.34	7.41	36.27	72.54	11.82	23.64	1.91
Alpha15	50	31.42	62.84	13.56	27.12	5.02	25.07	50.14	23.79	47.58	1.14
Alpha16	50	39.23	78.46	6.02	12.04	4.75	32.78	65.56	13.25	26.50	3.97
Alpha17	50	37.63	75.26	5.40	10.80	6.97	29.11	58.22	18.28	36.56	2.61
Alpha18	50	39.27	78.54	3.90	7.80	6.83	38.55	77.10	9.45	18.90	2.00
Alpha19	50	37.12	74.24	6.90	13.80	5.98	31.5	63.00	14.15	28.30	4.35
Alpha20	50	42.65	85.30	1.25	2.50	6.10	39.45	78.90	3.90	7.80	6.65
Alpha21	50	39.89	79.78	4.26	8.52	5.85	34.00	68.00	12.33	24.66	3.67

Sulphur: The data showed significant variances in S mg/kg, resulting from variations of the 30s and 80s, with a proven variation of 15.8% and 13.7%, respectively. The findings from Figures 25 (1,2) and 26 (1,2) were consistent with the results shown in Tables 15 and 16 of bran%. The data indicated that the greatest levels of bran percentage were detected in the 80s, and the differences were statistically significant with a $P < 0.05$.

Calcium: The calcium mineral, with a ca mg/kg concentration, did not exhibit significant differences ($P < 0.05$) between the 30s- and 80s-time units. The average calcium concentrations for the *S. bicolor* race were 402.5 mg/kg and 527.4 mg/kg, while for the Kafir race, they were 433.1 mg/kg and 573.2 mg/kg, as shown in Figures 25 (1,2) and 26 (1,2). The data was contrary to a variation in bran% of 34.2% and 28.2% resulting from the 30s- and 80s-time units, as shown in Tables 15 and 16.

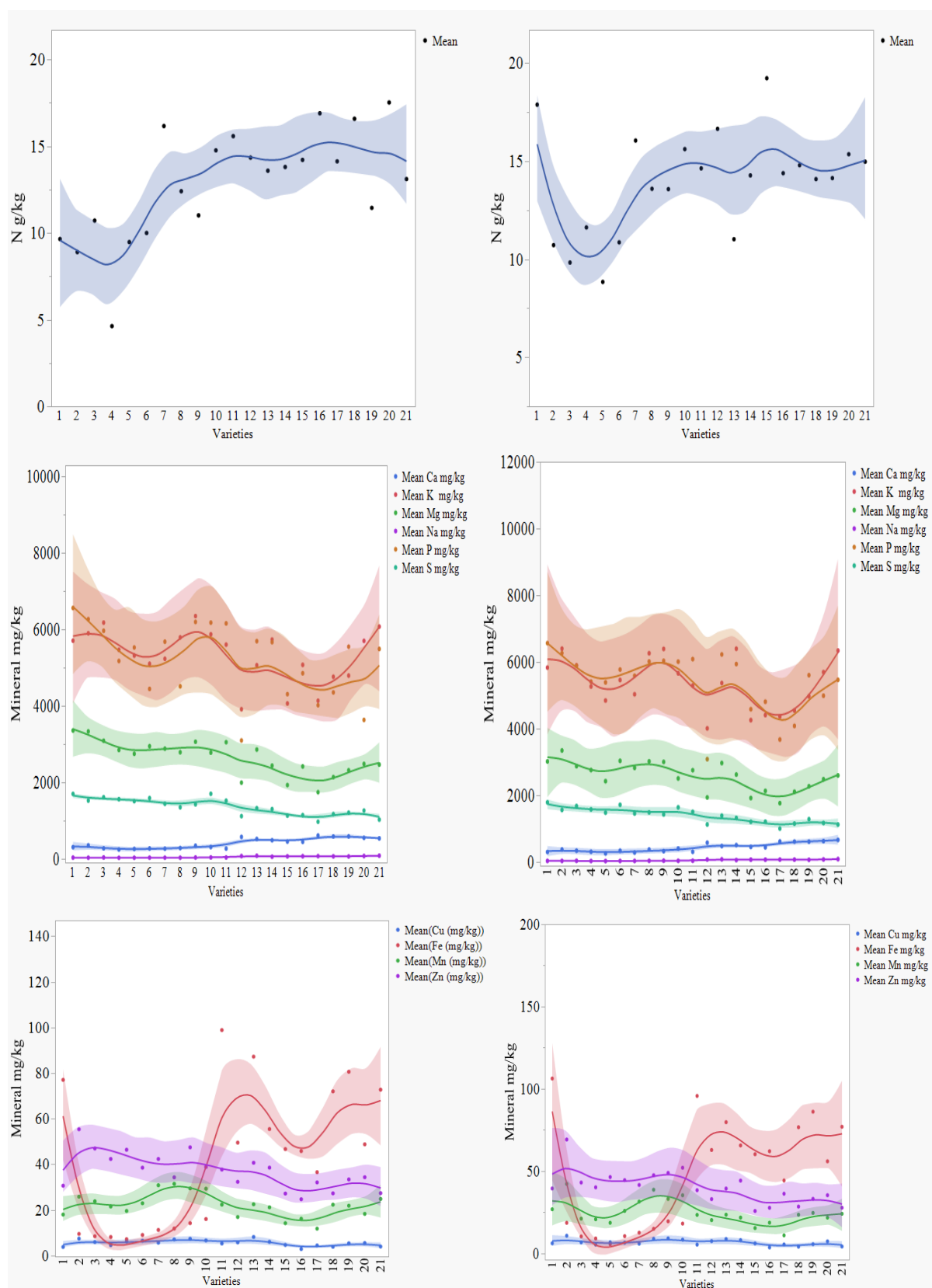
Magnesium: The analysis of the findings did not reveal any significant variation ($P < 0.05$) between the results stated from the 30s- and 80s-time unit, as they both had average values of 2648.2 mg/kg and 2584.8 mg/kg, respectively, for *S. bicolor*. Similarly, the average values in the Kafir race were 2156.7 mg/kg and 2168.1 mg/kg for the different time units. These results are depicted in Figures 25 (1,2) and 26 (1,2).

The examination of the data (Figure 26 (1-2)) demonstrated a decrease in Mg mg/kg contents among some samples of Kafir race resulting from the 80s, which was contrary to the dehulling procedure (bran%) indicated in Table 16.

Sodium: The findings revealed Na mg/kg variations among different varieties. The range of variation was observed to be from 30s to 80s at a concentration of 1.5%, as shown in Figure 25 (1-2) for the *S. bicolor* race. Similarly, the observed variation in sodium mineral amounts, as shown in Figure 25 (1-2), was between the 30s and 80s. Furthermore, an increase in sodium mineral amounts in Kafir was recorded at a concentration of 3.5%, coinciding with the peeling findings in Tables 15 and 16.

Table 16. Result of the applied husking procedure on the *Kafir* race inbred line

Samples	weight (g)	30 sec					80 sec				
		Endosperm (g)	Endosperm (%)	Bran (g)	Bran (%)	Waste (g)	Endosperm (g)	Endosperm (%)	Bran (g)	Bran (%)	Waste (g)
Alpha22	50	38.81	77.62	4.22	8.44	6.97	36.15	72.30	8.94	17.88	4.91
Alpha23	50	31.69	63.38	2.85	5.70	15.46	30.74	61.48	7.81	15.62	11.45
Alpha24	50	29.7	59.40	1.04	2.08	19.26	28.04	56.08	4.87	9.74	17.09
Alpha25	50	24.87	49.74	4.61	9.22	20.52	23.04	46.08	11.72	23.44	15.24
Alpha26	50	28.82	57.64	3.09	6.18	18.09	27.45	54.90	6.85	13.70	15.70
Alpha27	50	37.30	74.60	6.37	12.74	6.33	36.35	72.70	13.62	27.24	0.03
Alpha28	50	30.64	66.61	8.58	18.65	6.78	27.68	60.17	16.90	36.74	1.42
Alpha29	50	40.08	80.16	2.70	5.40	7.22	35.61	71.22	12.64	25.28	1.75
Alpha30	50	31.3	62.60	1.48	2.96	17.22	32.26	64.52	4.80	9.60	12.94
Alpha31	50	31.37	62.74	1.10	2.20	17.53	30.80	61.60	5.22	10.44	13.98
Alpha32	50	27.72	55.44	2.21	4.42	20.07	26.81	53.60	7.66	15.32	15.54
Alpha33	50	31.09	62.18	1.47	2.94	17.44	30.05	60.10	6.16	12.32	13.79
Alpha34	50	34.57	69.14	3.15	6.30	12.28	30.05	60.10	11.99	23.98	7.96
Alpha35	50	38.07	76.14	1.72	3.44	10.21	37.33	74.66	6.95	13.90	5.72
Alpha36	50	38.89	77.78	1.70	3.40	9.41	36.07	72.14	7.28	14.56	6.65
Alpha37	50	29.86	59.72	2.05	4.10	18.09	29.54	59.08	8.15	16.30	12.31
Alpha38	50	29.60	59.20	2.26	4.52	18.14	30.96	61.92	7.85	15.70	11.19
Alpha39	50	23.78	47.56	2.95	5.90	23.27	26.60	53.20	6.52	13.04	16.88
Alpha40	50	22.02	44.04	2.42	4.84	25.56	21.15	42.30	7.73	15.46	21.12
Alpha41	50	38.35	76.70	2.99	5.98	8.66	33.25	66.50	8.35	16.70	8.40
Alpha42	50	38.74	77.48	5.15	10.30	6.11	37.83	75.66	6.69	13.38	5.48
Alpha43	50	38.84	77.68	3.93	7.86	7.23	36.40	72.80	9.26	18.52	4.34
Alpha44	50	39.17	78.34	3.21	6.42	7.62	37.4	74.8	9.91	19.82	2.69
Alpha45	50	36.87	83.80	2.65	6.02	4.48	32.24	73.27	9.77	22.2	1.99
Alpha46	50	28.24	56.48	2.82	5.64	18.94	25.99	51.98	10.51	21.02	13.50
Alpha47	50	38.64	77.28	4.4	8.80	6.96	36.27	72.54	10.91	21.82	2.82
Alpha48	50	30.66	61.32	2.84	5.68	16.50	29.3	58.60	7.55	15.10	13.15
Alpha49	50	32.60	65.20	3.71	7.42	13.69	26.37	52.74	13.14	26.28	10.49
Alpha50	50	33.03	66.06	10.07	20.14	6.90	30.65	61.30	17.40	34.8	1.95
Alpha51	50	32.51	65.02	5.12	10.24	12.37	30.46	60.92	9.23	18.46	10.31



(1)

(2)

Figure 25. The average mineral component analysis of the *S. bicolor* race attributed to diverse varieties and regions, referring to (1) 30s and (2) 80s-time units, $P \leq 0.05$

Microminerals

Iron: The results from Figures 25 (1,2) and 26 (1,2) indicated that the bran fraction had the highest Fe mg/kg content. Specifically, the Fe content resulting from 30s and 80s was recorded at 139.6 and 183.4 mg/kg for *S. bicolor* and 132.9 and 139.2 mg/kg for the Kafir race, as shown in Figures 25 (1,2) and 26 (1,2). These findings were statistically significant, with a $P < 0.05$.

Zinc: The revealed results of Zn mg/kg contents showed that the employed dehulling process was significantly impacted by the 30s and 80s time units when *S. bicolor* showed an average of 37.1 mg/kg and 40.0 mg/kg, as well as Kafir race presented an average of 31.7 mg/kg and 34.7 mg/kg, respectively, as showed in Figures 25 (1,2) and 26 (1,2), proven a significance value of $P < 0.05$. The findings were consistent with the peeling findings outcomes in Tables 13 and 14.

Copper: Based on Figures 25 (1,2) and 26 (1,2) data, the Kafir race had the highest Cu mg/kg content level, averaging 6.2 to 6.8 mg/kg. The *S. bicolor* race had Cu mg/kg contents ranging from 5.6 to 6.6 mg/kg. These ranges were determined from 30s- and 80s-time units. The analyzed findings did not demonstrate a significant difference, with $P < 0.05$. Additionally, the Cu mg/kg levels contradicted the peeling results in Tables 15 and 16.

Manganese: The manganese (Mn) content in sorghum races (*S. bicolor* and Kafir) in Figures 25 (1,2) and 26 (1,2) did not show a statistically significant value ($P < 0.05$). The variation observed was 13.6% for *S. bicolor* and 18.5% for Kafir. These findings were obtained from the 30s- and 80s-time units, which contradicted the results of the peeling findings (Tables 15 and 16). The findings were evaluated using the endosperm (%) and the bran (%) recorded data.

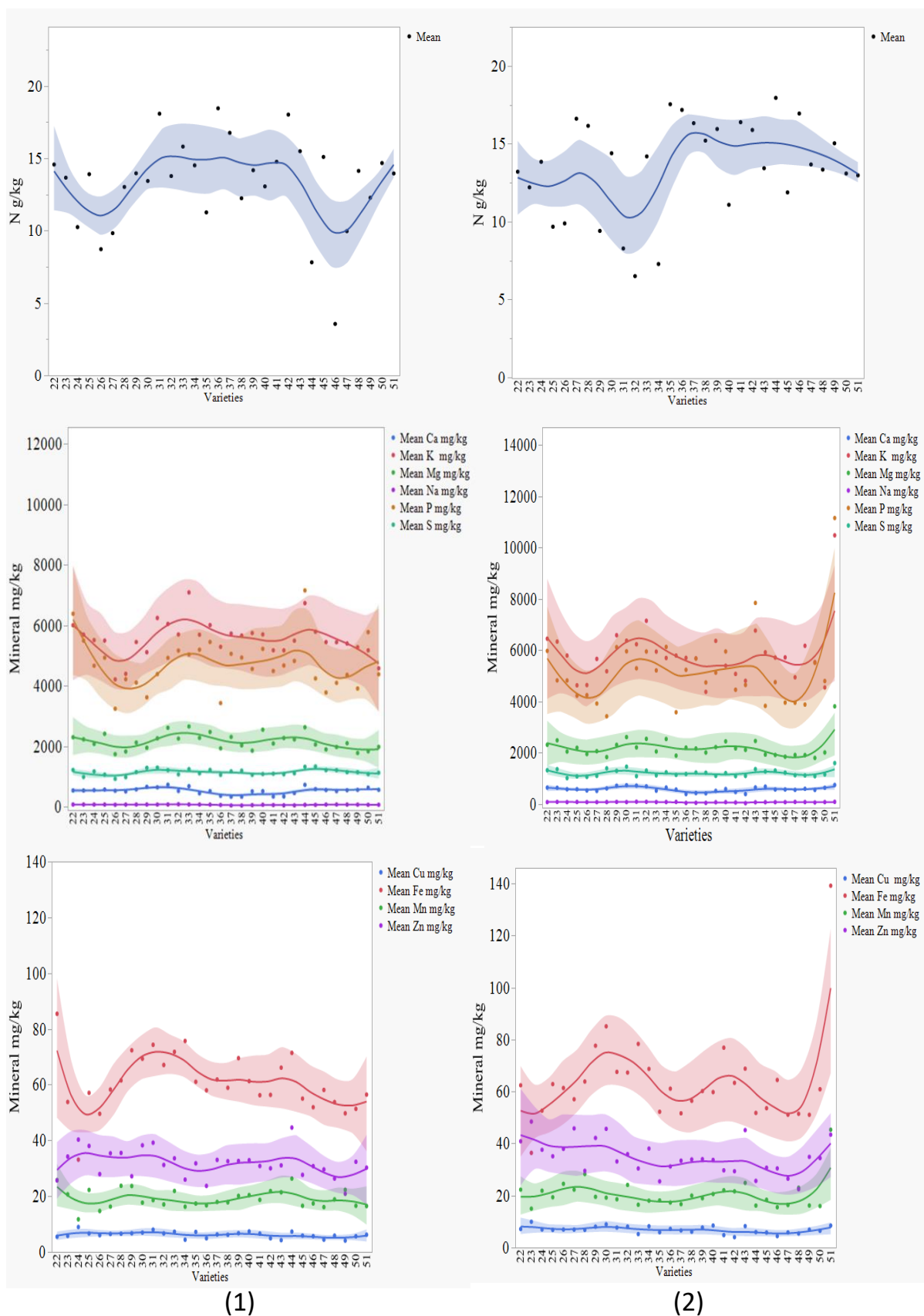


Figure 26. The average mineral component analysis of the Kafir race attributed to diverse varieties and regions, referring to (1) 30s and (2) 80s time units, $P \leq 0.05$

4.2.1.3. *P. miliaceum* varieties

Macro-mineral

Protein: The impact of the HFTU technique was evaluated based on the implications of 30s and 50s time units Figure 27 (1-2) and Table 18. The revealed result of the crude protein was significantly influenced by the two utilized time units ($P < 0.05$); according to (Table 17) the 50s proved a positive dehulling process mechanism, which is evidenced by the reduced waste (g) amounts among Biserka, Rumenka, and Gyöngyszem within an average of (7.3, 4.6, and 5.5) g in case of 30s reduced to (5.0, 2.7, and 3.2)g in case of 80s. When the Rumenka variety demonstrated the highest average of (69.9 -75.9) g/kg implied from the utilized time units, as were demonstrated variance of 5.0% among all *P. miliaceum* varieties, as shown in Figure 27 (1-2).

Phosphorus: The P mg/kg levels in Gyöngyszem, Biserka, and Rumenka were measured within 4479.8, 4271.8, and 4104.1 mg/kg, respectively. 30s time units recorded these measurements. The average sequence values within the set 8923.5, 8296.2, and 7241.6 mg/kg were identical in the case of 50s, with a variance of 47.4% of the two-time units.

Potassium: The potassium (K) mineral content levels varied among the three examined varieties, namely Biserka, Gyöngyszem, and Rumenka. These variations can be represented by the observed percentage differences of the 30s and 50s in each variety, which are as follows: Biserka (93.1% - 85.5%), Gyöngyszem (95.5% – 91.2%), and Rumenka (94.4% - 89.3%). These findings are explained in Table 15 and depicted in Figure 27 (1-2), with a significance value of $P < 0.05$. The observed variations of 49.4% in potassium levels were attributed to the different time units of 30s and 50s.

Sulphur: The analysis revealed that the Biserka variety had the lowest sulphur content, measured at S mg/kg, among all the tested varieties. This conclusion is shown in Figure 27 (1-2). The average sulphur content ranged from 1898.5 to 24449.9 mg/kg, based on the 30s and 50s.

The average S mg/kg concentration, as shown in Figure 27 (1-2), corresponds to the dehulling values reported in Table 17.

Table 17. Result of the applied husking procedure on *P. miliaceum* grain varieties

Samples	weight (g)	30 sec					50 sec				
		Bran (g)	Bran (%)	Endosperm (g)	Endosperm (%)	Waste (g)	Bran (g)	Bran (%)	Endosperm (g)	Endosperm (%)	Waste (g)
Biserka	50	2.75	5.52	40.35	80.7	7.38	5.67	11.34	39.25	78.5	5.08
Gyöngyszem	50	1.95	3.91	43.41	86.82	4.64	3.82	7.64	43.42	86.84	2.76
Rumenka	50	2.30	4.62	42.11	84.22	5.59	4.50	9.01	42.25	84.50	3.25

Calcium: The study found that the Ca mg/kg contents were significantly affected by the HFTU technique. Specifically, the 80s treatment negatively impacted the Ca mg/kg contents of the Rumenka and Gyöngyszem varieties. The average Ca mg/kg contents decreased from 4481.1 mg/kg and 4877.9 mg/kg in the 30s treatment to 3862.3 mg/kg and 2195.9 mg/kg in the 50s treatment, as shown in Figure 27 (1-2). This difference was statistically significant, with a significance value of $P < 0.05$. Interestingly, these results contradict the peeling results presented in Table 17.

Magnesium: The results of the Mg mg/kg concentrations in Figure 27 (1-2) corresponded to the outcomes of the peeling process, as shown in Table 17. Using 50s led to a higher level of Mg mg/kg than 30s, with a statistically significant difference at a significant level of $P < 0.05$. That was evidenced by an average of 2240.9 mg/kg and 4481.9 mg/kg in Figure 27 (1-2).

Sodium: The Na mg/kg contents were significantly affected by the 50s-time unit, as seen in Figure 27 (1-2), with a significance value of $P < 0.05$. Based on the recorded averages by Biserka, Rumenka, and Gyöngyszem varieties, the values were found to be (172.0, 148.6, and 142.8) mg/kg, respectively, after 30s-time units. Similarly, after 50s-time units, the averages were (344.0, 297.3, and 285.7) mg/kg, respectively. These results are depicted in Figure 27 (1-2) and are aligned with the peeling results in Table 17 ($P < 0.05$).

Microminerals:

Iron: The Fe mg/kg content varied across the tested varieties, as shown in Figure 27 (1-2). The average Fe mg/kg content was 77.2 mg/kg for variety 30s and 137.8 mg/kg for variety 50s. These averages were calculated without sorting the fractions (bran or endosperm), as indicated in Table 17.

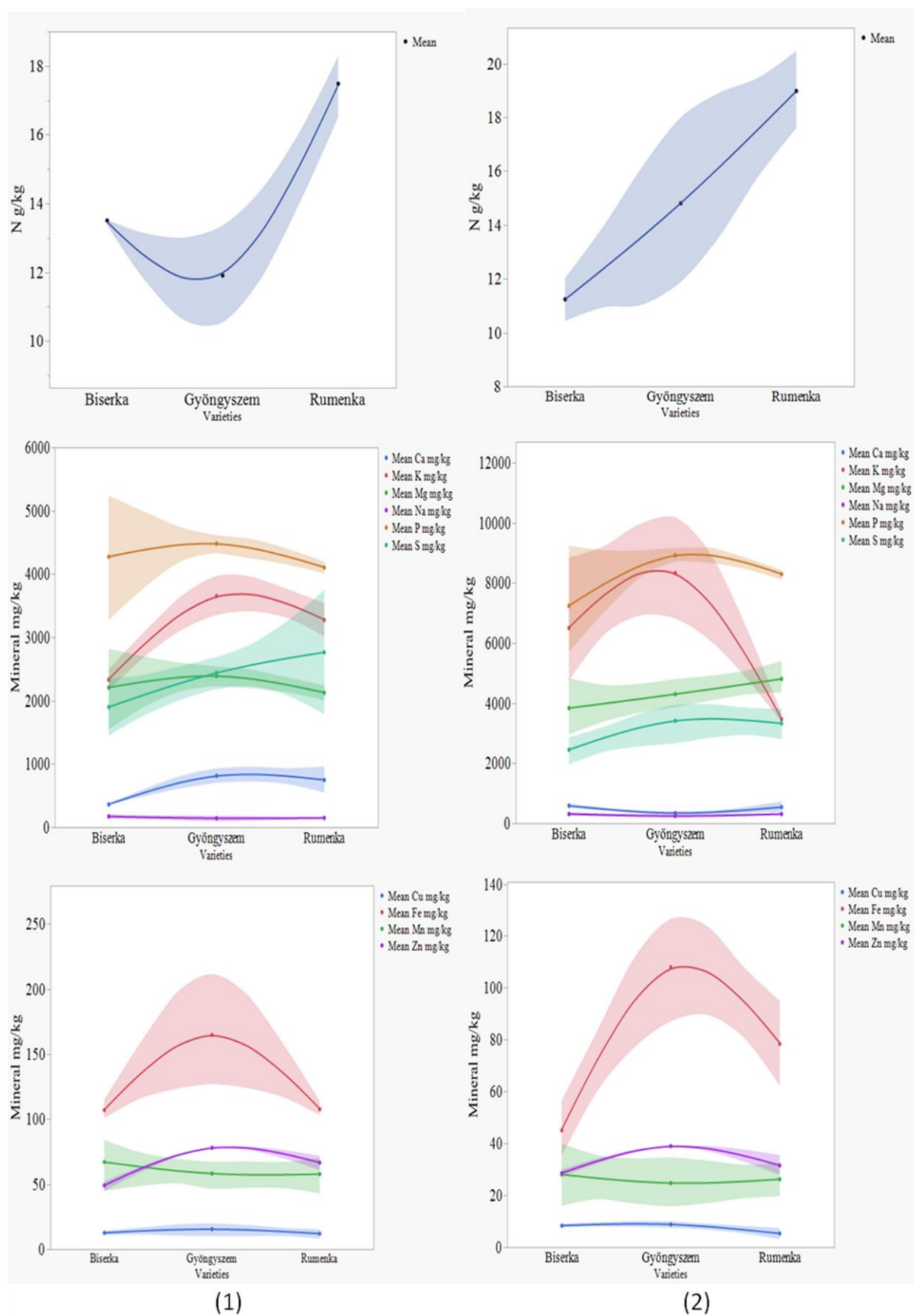


Figure 27. The average mineral component analysis of diverse *P. miliaceum* varieties attributed to diverse varieties and regions, referring to (1) 30s and (2) 50s-time units, $P \leq 0.05$

Zinc: The highest average of Zn mg/kg resulted from employed time units of the 30s and 50s indicated by the Gyöngyszem variety within an average of the 30s- and 50s-time units within 234.1 mg/kg and 468.1 mg/kg as shown in Figure 27 (1-2) and presented a variation of 90.0%.

Copper: The Cu mg/kg contents showed a reconcentration due to the increasing number of time units per (Second), as indicated by the highest consequence averages resulting from the 30s and 50s (Table 17) by the Gyöngyszem, Biserka, and Rumenka within (52.9, 50.1, and 31.8) mg/kg, respectively, increasing to (75.5, 70.2, and 57.6) mg/kg, respectively.

Manganese: The manganese (Mn) mineral content varied depending on the 30s and 50s when they occurred within an average range of 26.3 mg/kg and 52.7 mg/kg, as shown by the different *P. miliaceum* varieties in Figure 27 (1-2), with a significant level of $P < 0.05$. The Mn mg/kg level shown in Table 17 was consistent with the results of the dehulling process.

4.3. Results of the husking process attributed to various varieties and regions

The nutritional qualities of various areas and varieties were analyzed using a new method called the Husking Fraction Time Unite (HFTU) approach. The technique was performed in the 30s and 80s. The research inquiry used three data sets specified in Appendix 1. The investigation analyzed nutritional components such as thousand kernel weight (TKW), total protein, ash, dietary fiber, P, K, Ca, S, Mg, Cu, Fe, Na, Zn, and Mn. Additionally, from three different regions, tannin and colour profile measurements were partially conducted for eight similar varieties, including ES Föehn, ES Monsoon, and AS1 2021 IMI. These varieties were compared to other sorghum grain varieties, such as Alföldi1 and Farmsugro180 from Karcag and Nyíregyháza, as well as relevant nutritional profiles of *P. miliaceum* grain varieties sourced from Nyíregyháza.

Due to the variety of crop grains, the whole grain analysis was assessed using descriptive statistical analysis. The results are briefly discussed and given in Appendix 4-14.

4.3.1. Variability of thousand kernel weight (TKW) implied from the HFTU process

The study's results revealed a significant decrease in the TKW (g) of *S. bicolor* and *P. miliaceum* products after applying the HFTU technique. This reduction in TKW was observed across the products' whole grains (hummer) and husked grains endosperm (grits), as shown in Tables 19 and 20. We provided the mean TKW (g) for the whole grain samples, considering the

practical implications of this decrease in TKW for flour quality and its influence on phytochemical, milling, pasting, and gastronomic attributes.

4.3.2. Estimation of crude protein (N) content implied from the HFTU process

Crude protein is an essential nutrient that can assess and reflect the quality of the cereal grain nutritional composition; according to Appendix 1, the findings showed a fluctuated range of crude protein among the examined whole grain varieties, which were demonstrated by the highest average of 17.0 g/kg in the red sorghum whole flour (ground) compared to 16.9 g/kg in the white sorghum whole flour (ground), the presented ranges were aligned to provided average of 16.9 g/kg by the sorghum whole flour from (retail source) linked to reported finding outcomes by (Adzqia et al., 2023), authors discussed sorghum white flour's nutritional and physicochemical characteristics and compared the average crude protein g/kg of *S. bicolor* and *P. miliaceum* (Tables 19 and 20).

P. miliaceum whole flour presented the highest average of N g/kg within 18.1 g/kg among the evaluated cereal grain products (Appendix 14), evaluated as lower than the revealed level of 19.9 g/kg in *P. miliaceum* whole grain flour (retail store).

Generally, the assessment of the implications of the husking process (HFTU) on the crude protein level was reflected in the redistribution and concentration of crude protein in the produced fractions of *S. bicolor* grains, as shown in Table 19 ($P < 0.05$).

As well as the ES Föehn variety (sorghum benchmark) from the Hortobágy region within an average of 18 g/kg compared to similar ES Föehn variety from Nyíregyháza and Esztár, when demonstrated averages within 15.0 g/kg and 17.0 g/kg, respectively, While Esztár region was presented with the highest average within 19 g/kg according to total protein implications from the HFTU process attributed to various regions, as shown in Table 18 with a significance value of ($P < 0.05$).

4.3.3. Variability of total dietary fiber (TDF) content implied from the HFTU process

According to the presented data in (Table 19), the (HFTU) positively impacted the TDF g/kg contents in the tested *P. miliaceum* fractions, as the findings showed a reconcentration of the higher amounts of the TDF g/kg in the bran than endosperm (grits). Dietary fiber content varied among whole and husked sorghum grain fractions, as illustrated in Tables 19 and 20. The AS1 2021 IMI variety from three regions exhibited the highest concentration of dietary fiber in the

endosperm (grits), which was 13.6% higher than in the bran. This finding is evidence for a nutritional redistribution of *S. bicolor* following the (HFTU) process, as suggested by the 30s and 80s time units with a significance level of $P < 0.05$, as explained in Tables 19.

According to other investigation achievements, the findings showed that the Hortobágy region had a higher TDF content than the Nyíregyháza and Esztár regions, with an average of 149 g/kg, as shown in Table 18.

Despite valuable insight into the nutritional profile of *P. miliaceum* and *S. bicolor* husked fractions, however, the implications of the other factors affecting the viability of the total dietary fiber-attributed HFTU process.

4.3.4. Variability of ash content implied from the HFTU process

The results of Tables 19 and 20 demonstrated the impact of the (HFTU) technique on the separation of the endosperm (grits) and the bran, as evidenced by the documented percentages of 19.0% and 23.0%, which indicate a 22.6% increase. Additionally, there was additional evidence that the husking process was adequate. For instance, at the levels that have been illustrated, the average percentage is implied from the 30s and 80s.

The proportion of whole grains (hummer) and husked products (TM05C) increased by 33.2% from the recorded averages of 15% and 21%, respectively, with a significance value of ($P < 0.05$). The results underscored the advantageous influence of the (HFTU) method on the concentration of ash content accumulation in both produced fractions of endosperm (grits) and bran. The revealed ash values were consistent with the reported value by (Keyata et al., 2021). The investigation reported that the sorghum ash range was 1.1%–2.4% lower than the revealed values related to the recent findings. Nevertheless, our revealed ash values were within 1.1%–2.8%, which aligned with the range of 1.3%–3.3% (Baholet et al., 2018). The findings indicated that the highest averages of 15 g/kg and 27 g/kg were recorded by Hortobágy regions based on region factor variance ($P < 0.05$), as detailed in Table 18.

4.3.4. Variability of macro-mineral (P, K, S, Ca, Mg, and Na) contents attributed to variety and region

The assessment of the Phosphorus (P) content was abundant in the examined grain varieties; however, the lowest average of 2339.7 mg/kg was observed by the GK Erzsébet variety. While the ES Monsoon variety has demonstrated the highest average of P mg/kg within 5315.6 mg/kg compared to other investigated varieties Appendix 4, the revealed finding was supported by the

recorded highest range of P mg/kg (3322.7 mg/kg to 5824.7 mg/kg) was shown among the same eight varieties from the different three regions (Appendix 1), compared to other *S. bicolor* grains from the various origin sources, which were recorded average from (2339.7 mg/kg to 3814.0 mg/kg), in comparison to *P. miliaceum* varieties, as their displayed range from (2857.7 mg/kg to 3374 mg/kg) within an average of 3129.9 mg/kg, which was a higher than the revealed average of 2625.9 mg/kg in the purchased *P. miliaceum* whole flour, as shown in Appendix 4. On the other hand, the Husking Fraction Time Unit (HFTU) process positively implied the P mg/kg contents in the measured grain varieties, which was evidenced by the highest average of 3601.9 mg/kg and 5247.7 mg/kg had resulted from 30s - and 80s-time units, within a variation of 46% (Table 17), with a significance value of $P < 0.05$.

The average of 6990.2 mg/kg was implied from the employed (HFTU) process in the *P. miliaceum* varieties, while the sufficiency of the dehulling process within 44.7% among the dehulled and ground grain of the *P. miliaceum* varieties (Tables 17 and 20), with a significance value of $P < 0.05$.

Furthermore, the findings showed that the highest average of P (5115 mg/kg) based on region was noticed in the Hortobágy site, as displayed in Table 18 and Figure 27.

The most interesting potassium (K) mineral findings can be presented by the lowest K mg/kg observed among *P. miliaceum* varieties, within 3761.9 mg/kg. That was met by a similar K (3521.1 mg/kg) range in the commercial millet whole flour and a lower K (6204.9 mg/kg) in the sorghum grain varieties from three regions, as detailed in Appendix 5 and Table 20.

Further finding outcomes were displayed by the highest K mg/kg average in the Nyíregyháza origin site, as shown in Table 26 ($P < 0.05$). In the case of *P. miliaceum*, the observed averages of the 30s and 80s were demonstrated within 3798.9 mg/kg and 6125.7 mg/kg, respectively, and a variation of 45.1%, according to Table 15 ($P < 0.5$).

The relevant findings of K mg/kg showed that the K mg/kg content had presented an acceptable range, which can reflect that the quality of the grains can fulfill the human dietary requirements, as was reported by the National Academies of Sciences, Engineering, (2019).

The study findings supported the concentration of Sulphur (S) mineral, that *P. miliaceum* had an abundant range of the total protein rich with amino acids containing sulphur (methionine) when the investigation outcomes showed the highest average of S mg/kg among the *P. miliaceum* varieties within 1432.4 mg/kg compared 1195.3 mg/kg was observed among the same sorghum grain varieties from three regions and an average of 1190.0 mg/kg among diverse commercial sorghum grain varieties (Appendix 6).

While the HFTU process significantly impacted S mg/kg content in *S. bicolor* varieties, when it showed increasing range from 899 mg/kg to 206 mg/kg as presented in Table 19 ($P < 0.05$), moreover the variation of the 30s and 80s was assessed within 18%, as the dehulling process. As was mentioned earlier, we promoted the ES Monsoon variety from various regions for the dehulling process due to its abundant levels of specific nutrient contents such as calcium (Ca) mineral.

When the varieties showed the highest Ca mg/kg content within 566.9 mg/kg; moreover, the supported finding to study measurement precision was noticed by the lowest average of Ca mg/kg among *P. millet* whole grain varieties (Appendix 8), which showed an average of 355.6 mg/kg in comparison to an observed average of 292.8 mg/kg in the commercial *P. miliaceum* whole grain flour.

On the other side of the study investigation, the HFTU process had a positive impact on Ca mg/kg content among the processed *P. miliaceum* grain varieties (Appendix 8), as the average of 429.1 mg/kg was implied from the dehulling process compared to the commercial husked *P. millet* grains within 175.1 mg/kg, which was proved the positive implication of the HFTU process on the reconcentration of Ca mg/kg in the processed *P. miliaceum* varieties. More evidence was shown by the implication of the husking process on the Ca mg/kg on the sorghum grain varieties (Table 18), with a significance value of $P < 0.05$, as was demonstrated by the highest revealed level of Ca mg/kg in the bran fraction within 1371.7 mg/kg in comparison to the revealed average of 603 mg/kg in the endosperm (grits) within ($P < 0.05$).

Based on the study objective, we underwent a calcium (Ca) mineral investigation attributed to the origin source, and the findings showed that the Nyíregyháza source has a higher level of Ca mg/kg within 830.0 mg/kg (Table 18).

The findings outcomes of the magnesium mineral contents were supported by the scientific concept background, which was reported that the sorghum grain with red kernel has a higher Magnesium mineral content than the *S. bicolor* grain with the white kernel, as evidenced within Averages of 1318.7 mg/kg for the Alföldi1 (red variety) and 1195.4 mg/kg for Farmsugro180 (white variety), as were demonstrated in Appendix 9. The findings referred to a positive impact of the HFTU process on the concentration of Mg mg/kg among the examined sorghum grain varieties when it displayed averages of 1379.8 mg/kg to 2681.0 mg/kg based on the whole grain to husked grains (Tables 19 and 20) with a significance value of $P < 0.05$.

The implication of Mg mg/kg in *P. miliaceum* based on the varieties was indicated by the lowest average among the examined grain varieties (Appendix 1 and 8). In contrast, averages of

2240.9 mg/kg and 4481.9 mg/kg were implied from the Mg mg/kg contents of the *P. miliaceum* husked grains attributed to the 30s and 80s, as shown in Table 17 and Figure 24. Moreover, the findings indicated a noticeable reduction in Mg mg/kg on the Gyöngyszem variety, recorded between 4045.9 mg/kg to 3434.6 mg/kg (Table 18), with a significance value of $P < 0.05$.

Sodium (Na) mineral results can be presented by the highest sequenced average recorded by the investigated varieties sourced from Hortobágy, Esztár, and Nyíregyháza within (44.5 mg/kg, 36.5 mg/kg, and 34.4 mg/kg), respectively. Despite the highest average observed by the same sorghum varieties from different regions, the Lupus variety demonstrated the highest Na mg/kg content within 112.0 mg/kg among all the tested whole grain varieties (appendix 10). The lowest average of 33.4 mg/kg was noticed by *P. miliaceum* whole grain (ground) based on the Na mg/kg concentration in the three varieties, which was lower than the provided average of 43.9 mg/kg of the *P. miliaceum* whole flour sourced from the retail store (Appendix 1).

On the other hand, the study investigation indicated that the HFTU process.

That significantly influenced the Na mg/kg content in the husked sorghum grain varieties, as detailed in Table 19 within the statistical variance of ($P < 0.05$), which attributed to the variability of the varieties. In a comparison of the implications of the HFTU process, the Hortobágy origin source showed the highest Na mg/kg concentration among the three measured regions, as shown in Table 16 ($P < 0.05$) as evidenced by a ratio of 0.38%, which is implied from the detected variation between the 30s- and 80s-time units.

According to a result of Cu mg/kg contents, the *P. miliaceum* whole flour (ground) showed the highest Cu mg/kg content levels among all examined grain products. The Cu mg/kg fluctuated among sorghum grain whole grain products (Appendix 10) when the frequencies average from (2.3– 3.8 mg/kg) were confirmed by an average of 3.2 mg/kg recorded by sorghum whole flour from retail stores (Appendix 1). At the same time, the result of the husked fraction of *P. miliaceum* showed an average of 2.3 mg/kg to 14.6 mg/kg implied from the HFTU process, specifically from the 30s- and 80s-time units (Table 14), with a significance value of ($P < 0.05$).

According to descriptive analysis of the iron (Fe) mineral Fe mg/kg content results in different *S. bicolor* and *P. miliaceum* husked products, as shown in Tables 14 and Appendix 11, the highest Fe mg/kg content was in red sorghum whole flour (ground) (44.6 mg/kg) compared to white sorghum whole flour (ground) (39.6 mg/kg). The presented range was aligned with the revealed range of whole flour within the average of 42.6 mg/kg sourced from retail stores.

As well as the *P. miliaceum* showed abundant Fe mg/kg contents within 56.3 mg/kg, which was proved by the implication of the HFTU process, as indicated by the mentioned increase among the whole grain, endosperm, and bran within (51.7 mg/kg, 106.0 mg/kg, and 175.0 mg/kg), were presented in Table 20 ($P < 0.05$). Despite abundant iron (Fe) mineral concentrations, the Biserka and Gyöngyszem varieties showed a noticeable reduction of 79.1 mg/kg to 77.3 mg/kg and 118.3 mg/kg to 88.0 mg/kg, considering the recorded decrease in Fe mg/kg the finding outcomes were demonstrated a positive impact of the HFTU process in redistribution and reconcentration of Fe mg/kg in examined cereal grains (Tables 19 and 20); furthermore, the concentration was aligned to a detected average of 53.9 mg/kg in the husked *P. miliaceum* sourced from the retail shop (Appendix 1).

The HFTU process significantly impacted Fe mg/kg contents in the tested sorghum grains within a variation of 62% implied from endosperm/bran, as detailed in Tables 15 and 26 ($P < 0.05$). At the same time, the comparison of the 30s and 80s revealed an average of 43.2 mg/kg and 59.6 mg/kg, respectively.

The findings of zinc (Zn) mineral concentration were presented by the highest recorded average by Biserka, Gyöngyszem, and Rumenka within 31.4 mg/kg, 29.3 mg/kg, and 27.8 mg/kg, respectively. They were sorted as a higher Zn mg/kg level than the 23.0 mg/kg level in *P. miliaceum* whole flour sourced from the retail store (Appendix 1 and 13).

The evaluation of Mn mg/kg contents was presented by the highest average of 21.5 mg/kg recorded by the same *S. bicolor* grain varieties from the three regions (Appendix 1). This average was higher than the revealed average of 15.1 mg/kg recorded by *P. miliaceum* whole grain (ground), confirmed by the lowest average of 10.0 mg/kg noticed in *P. miliaceum* whole flour sourced from (retail source) based on the presented data in Appendix 1 and 13.

While *P. miliaceum* showed variation between the whole grains (ground) and husked grains (fraction) within 21.9 mg/kg and 27.8 mg/kg within a ratio of 18% implied from the 30s- and 80s-time units as shown in Table 14 ($P < 0.05$).

Table 18. Sorghum grain nutritional contents on the whole grains and Husked grains based on the various regions

Variables	Whole grains (Hummer)				Husked grains (TM05C husker)			
	Hortobágy	Esztár	Nyíregyháza	P-value	Hortobágy	Esztár	Nyíregyháza	P-value
Total dietary fiber g/kg ⁻¹	134±23.0	134±18.0	134±17.0	0.3	149±12.3	138±14.1	139±8.2	0.05
Total protein g/kg ⁻¹	16±2.0	15±2.0	15±2.0	0.22	16±7.8	19±8.2	16±8.0	0.20
Ash g/kg ⁻¹	15±0.5	14±0.1	13±0.1	0.04	27±0.03	21±0.05	15±0.07	0.01
P mg/kg ⁻¹	4883±1193.0	5075±1096.0	4426±964.0	0.44	5115±3623.3	4482±3258.1	4995±3038.3	0.71
K mg/kg ⁻¹	5901±745.4	6175±849.4	7030±1180.0	0.04	5852±3202.2	5013±3013.6	6871±3509.0	0.05
S mg/kg ⁻¹	1280±633.8	1280±633.5	1234±403.2	0.73	1360±505.5	1264±319.8	1447±461.3	0.05
Ca mg/kg ⁻¹	519±120.2	502±104.8	507±127.2	0.59	1071 ±579.7	1061±557.0	830±544.9	0.02
Mg mg/kg ⁻¹	1356±211.9	1356±159.8	1400±163.6	0.67	2697±2114.1	2137±1303.1	3210±1209.0	0.05
Cu mg/kg ⁻¹	3±1.0	4±1.0	4±1.0	0.51	9±4.7	9±3.3	6±4.4	0.03
Fe mg/kg ⁻¹	66±9.1	54±6.5	53±5.3	0.01	59±33.9	66±38.5	46±32.5	0.05
Zn mg/kg ⁻¹	20±1.3	24±2.3	22±3.0	0.05	34±25.9	28±7.0	21±14.4	0.04
Na mg/kg ⁻¹	35±13.5	35±10.5	44±13.5	0.14	116±32.2	108±27.5	93±22.2	0.03
Mn mg/kg ⁻¹	21±6.4	28±5.1	20±5.5	0.02	33±26.0	37±24.0	30±22.0	0.53

* Values 0 refers to the processed grains by hammer mill, while 30s and 80s refer to the husked grains by TM05C, husker. mean± SD, mineral contents were calculated from three replication readings, while the total protein and total dietary fiber was calculated from two replication readings, P≤0.05

Table 19. Process-based descriptive data analysis of the nutritional profiles of whole flour (hummer) and husked grain (HFTU) varieties of *S. bicolor* grain varieties

Variables	Grain parts	T KW g	Total protein g/kg ⁻¹	TDF g/kg ⁻¹	Ash g/kg ⁻¹	P mg/kg ⁻¹	S mg/kg ⁻¹	Ca mg/kg ⁻¹	K mg/kg ⁻¹	Mg mg/kg ⁻¹	Fe mg/kg ⁻¹	Na mg/kg ⁻¹	Zn mg/kg ⁻¹	Cu mg/kg ⁻¹	Mn mg/kg ⁻¹
H4	1	32	19.0±0.9	163±10.0	23.7±0.2	1709±1569.0	1076±174.2	397±38.9	2419±971.8	1155±252.3	24±9.0	80±8.2	9±4.8	5±2.0	9±4.0
	2	-	1.6±0.2	172.3±4.0	28.4±0.1	7657±2298.7	1511±474.9	1854±148.2	9848±71.5	2327±129.4	99±1.6	132±36.3	59±8.7	13±3.6	46±6.1
E4	1	15	15.6±0.7	137.0±13.0	18.8±0.3	3038±368.6	1282±189.3	943±635.4	4289±778.7	2092±212.4	21±5.3	95±11.6	11±3.9	5±1.5	11±2.5
	2	-	14.0±0.8	145.4±3.1	24.4±0.1	8706±4183.9	1575±393.6	1336±543.1	9891±95.9	3633±401.0	86±34.5	98±14.7	60±31.0	9±0.2	51±7.2
Ny4	1	11	15.1±0.1	12.4±4.2	14.3±0.7	1620±1483.7	1032±95.0	516±203.0	2258±649.4	1632±236.0	24±10.0	115±35.6	9±4.8	9±0.35	9±3.7
	2	-	14.2±0.3	13.9±4.3	17.0±0.1	8416±274.2	1596±73.5	1451±33.6	9076±1195.0	3431±139.4	80±44.6	101±15.6	45±5.0	16±0.4	52±2.6
H7	1	21	1.7±0.2	15.2±11.0	25.2±0.4	2989±162.0	1111±266.0	1205±611.1	3014±537.4	1686±274.3	50±13.5	123±1.3	14±1.2	6±1.3	14±1.9
	2		1.6±1.0	14.7±2.2	32.8±0.1	8142±2960.8	1333±226.7	1448±203.3	7662±1393.3	3831±560.7	77±58.6	103±2.6	52±18.2	10±0.7	54±17.5
E7	1	17	1.5±0.1	14.2±5.7	18.4±0.8	2396±427.3	958±206.9	434±91.7	2971±301.1	1254±200.4	40±16.2	81±18.7	11±6.3	6±1.1	13±0.2
	2	-	1.5±0.3	12.9±2.6	22.1±0.2	7123±607.5	2061±543.1	961±432.3	7640±1133.1	4004±262.6	34±3.9	101±25.3	37±4.2	13±4.4	31±15.2
Ny7	1	23	1.5±0.8	11.4±1.8	9.1±0.6	1823±84.4	1214±400.3	809±37.8	5886±417.2	1717±1172.0	40±2.9	111±15.1	7±0.8	6±0.9	17±4.8
	2	-	1.6±2.1	11.2±6.5	10.9±0.2	8612±1731.0	1649±248.8	1760±248.1	8432±103.1	3912±532.8	88±11.9	86±8.3	36±0.1	6±2.6	59±9.2
H1	1	12	1.4±0.6	13.8±13.2	24.4±0.2	1457±623.2	899±77.2	415±31.5	2236±615.1	600±145.2	28±7.3	75±11.9	9±4.6	4±0.1	6.3±1
	2	-	1.8±0.1	13.2±12.2	29.3±0.2	5904±2292.1	1478±1.4	872±14.1	8090±115.2	4089±476.0	84±2.5	133±10.9	36±2.8	9±0.09	46±6.3
E1	1	15	1.5±1.1	12.81±11.3	19.8±0.2	1191±876.3	934±82.2	351±27.4	2339±108.2	1502±598.0	23±8.7	87±15.8	5±1.9	6±0.1	6±6.5
	2		1.7±0.8	12.2±15.1	23.7±0.1	9004±537.1	2105±510.0	1594±359.7	9860±744.4	4320±2235.1	103±91.0	154±36.8	47±15.0	15±3.8	75±2.2
Ny 1	1	17	1.4±0.2	11.2±15.0	16.3±0.5	1682±732.0	1026±90.2	362±51.9	2199±361.0	1480±540.7	28±4.8	103±30.2	11±3.7	5±1.5	11±5.0
	2	-	1.5±0.01	12.4±2.3	19.5±0.1	6080±3007.4	1551±104.0	1071±245.2	8301±195.7	3591±1002.1	97±23.2	120±34.6	40±4.0	20±11.7	154±37.2
P-value (Endosperm+bran)		-	0.05	0.05	0.04	0.05	0.01	0.03	0.27	0.05	0.03	<.001	0.04	0.003	0.17

* Numbers refer to 1: Endosperm, 2: Bran, mean values presented mean± SD were calculated from three replications on a dry basis, values with a red colour refer to a reduction in mineral level after the (HFTU) process, TKW, and mineral content were calculated from three replication readings, while the total protein and total dietary fiber were calculated from two replication readings, $P \leq 0.05$

Table 20. Process-based descriptive data analysis of the nutritional profiles of whole flour (hummer) and husked grain (HFTU) varieties of *P. millet* grain varieties

Variables	grain	TKW g	Protein g/kg ⁻¹	TDF g/kg ⁻¹	P mg/kg ⁻¹	S mg/kg ⁻¹	Ca mg/kg ⁻¹	K mg/kg ⁻¹	Mg mg/kg ⁻¹	Fe mg/kg ⁻¹	Na mg/kg ⁻¹	Zn mg/kg ⁻¹	Cu mg/kg ⁻¹	Mn mg/kg ⁻¹
Bierka	1	5.3	12±0.06	16 ± 0.01	3729±996.3	2736±223.7	429±83.6	3136±1144.9	2015±735.6	79±20.8	19±66.3	40±14.5	11±3.9	67±24.3
	2	-	11±0.10	466±0.01	8587±3135.4	1368±111.8	344±203.5	6859±4695.5	4605±1681.4	77±51.7	34±122.0	36±5.7	9±0.3	17±6.3
Rumenka	1	5.3	10±0.27	92±0.01	6644±2418.5	4126±9.1	381±96.0	5017±1500.4	2650±755.1	106±6.1	64±3.0	57±22.5	15±6.8	52±19.0
	2	-	16±0.05	561±0.01	6426±2346.3	2017±45.6	709±296.0	8166±4442.5	3918±1430.6	176±103.8	30±12.6	59±21.3	6±1.5	24±12.6
Gyöngyszem	1	4	15±0.04	243±0.01	6574±2079.2	3386±619.2	491±169.8	3244±55.4	4046±2055.1	118±18.4	21±138.9	56±19.0	14±3.4	56±20.4
	2	-	19±0.11	701±0.01	5958±2175.6	1739±359.7	988±40.7	3351±493.3	3435±1254.1	88±35.1	15±71.2	39±14.3	2±0.1	21±3.6
P-value	-	-	0.01	<.001	0.03	<.001	0.009	0.01	0.4	<.001	0.02	0.04	0.46	0.49

* Numbers refer to 1: Endosperm, 2: Bran, mean values presented mean± SD were calculated from three replications on a dry basis, values with a red colour refer to a reduction in mineral level after the (HFTU) process, TKW, and mineral content were calculated from three replication readings, while the total protein and total dietary fiber were calculated from two replication readings, P ≤ 0.05

4.4. Correlation between the mineral components and the husked *S. bicolor* and *P. miliaceum* grain varieties

We performed a discriminant analysis (DA) test to assess the relationships and distinguishing correlation features between mineral composition, variety, and region factor of the examined husked fraction under a similar 30s-time unit; the analysis evaluated the precision of data analysis, when demonstrated relationships within a total correlation of 67.7% between C1 (52.8%) and C2 (14.9%), indicating a good connection between the main data items. Moreover, the classic plot displayed the average ellipses, normal 50% contours, and biplot rays. Furthermore, the discriminant analysis test did not show either correlation between sorghum grain varieties or *P. miliaceum* itself; based on the above-detailed information, the accumulation of nutrient contents fluctuated among the three tested *P. miliaceum* fractions (endosperm and bran) when the finding indicated a reduction in some nutrient compositions such as measured micromineral (Na, Fe, Cu, Zn, and Mn) as appeared in Figure 28 ($P < 0.05$). A substantial correlation was seen between the *P. miliaceum* and similar sorghum grain varieties from different sources involving Nyregyháza, Esztár, and Hortobágy, as the revealed variation detailed in Table 16. Consequently, the discriminant analysis diagram indicated a weak correlation (negative) between the potassium (K) mineral and other tested macro-micromineral Figure 23. As well as a weak correlation (negative) was also noticed by the E1 and Ny4 varieties, which were contrary to the H4 variety; the variety showed a strong relationship with other examined sorghum product varieties attributed to 30s-time units. The discriminant analysis revealed a substantial linear association among minerals, such as S, Cu, Fe, Na, Ca, Mg, and Zn in the C1 within a correlation coefficient of 52.8%. In contrast, the other minerals, such as (K, Ca, Mg, and Mn) were exhibited weak correlations (negative) in the C2 (14.9%). The mineral composition and the origin sites, including Nyíregyháza, Esztár, and Hortobágy, were found to have a strong relationship, according to the discriminant analysis. The unprocessed form of the data was used to illustrate the correlation between the analyzed variables, as displayed in Figure 28.

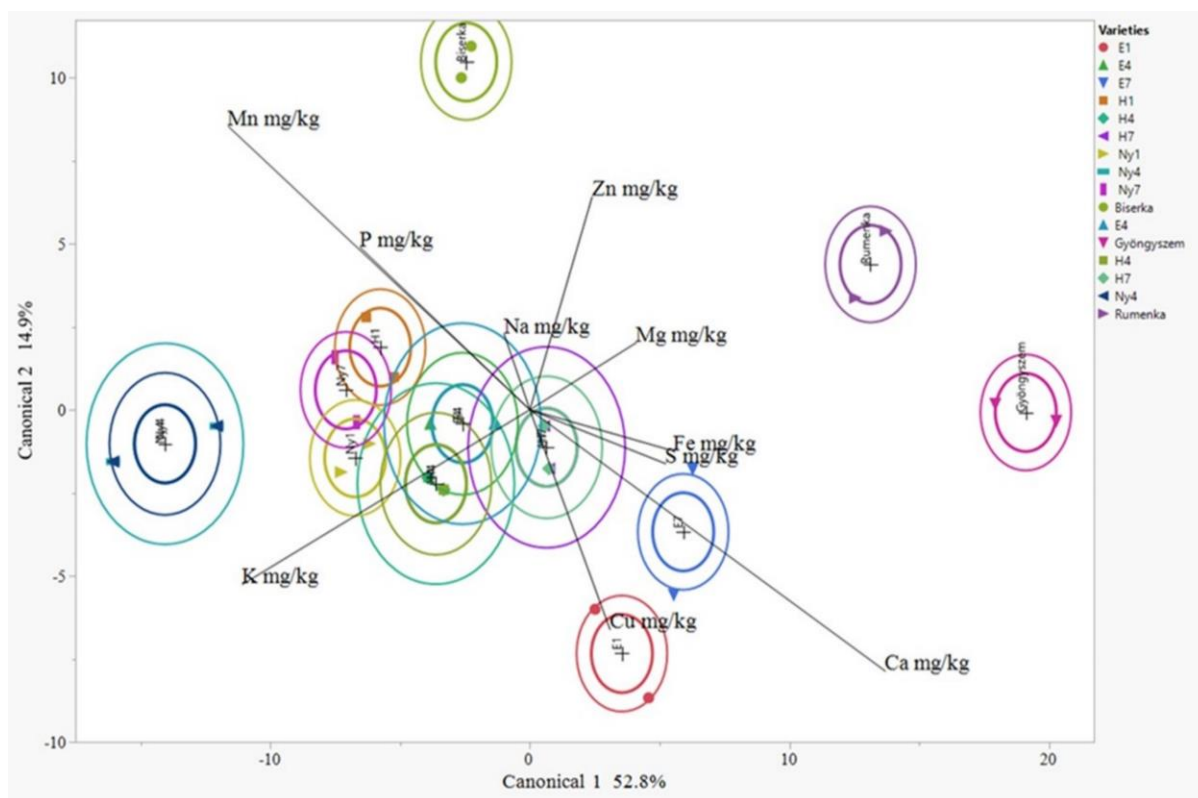


Figure 28. Discriminant analysis of mineral components and husked *S. bicolor* and *P. miliaceum* grain varieties attributed to 30s-time unit, $P \leq 0.05$

4.4.1. Assessment of the colour profile of the husked *S. bicolor* and *P. miliaceum* grain fractions

The colour measurements were considered the most accomplished objective of the precision of the implied target of the husking process. We performed the tannic acid level for whole cereal grains (Figure 30) besides the variance of 30s and 50s in the case of *P. miliaceum* grain varieties as shown in (Figure 31) and 30s and 80s for sorghum grain varieties according to (Figure 32). The findings were lined up and confirmed the precision of results outcomes from the Konica Minolta spectrometer camera (Figure 10).

Table 21. Tannic Acid % levels among brown and red *S. bicolor* and *P. miliaceum* whole grain varieties

Varieties	Tannic acid (m/m)%
K1	0.102
H 1	0.106
E 1	0.100
Ny 1	0.034
H 4	0.152
E 4	0.049

Ny 4	0.085
H 4	0.077
E 7	0.057
Ny 7	0.172
K 1/4	0.564
Ny 1/4	0.149
Gyöngyszem	0.183

According to Appendix 4 and Figure 24, the measurements of the tannic acid were aligned to the revealed colour spectrum of b^* ; for instance, the varieties with red kernel colour of *S. bicolor*, and *P. miliaceum* husked product varieties such as ES Föehn, ES Monsoon, and AS1 2021 IMI from three different regions (Tables 4 and 25), and Rumenka variety (*P. miliaceum*), showed the low values (Y) spectrum located on the dark spectrum <60 and >70 (Figure 30) and spectrum of yellow colour (b^*), which were confirmed by positive values, the results were aligned to (Komyshev et al., 2020). The study outcomes were coordinated to the yellow spectrum (b^*) with tannic acid levels as phenolic compounds, and their varied concentration can be attributed to the genetic variability of the respective cereal grain varieties (Table 19).

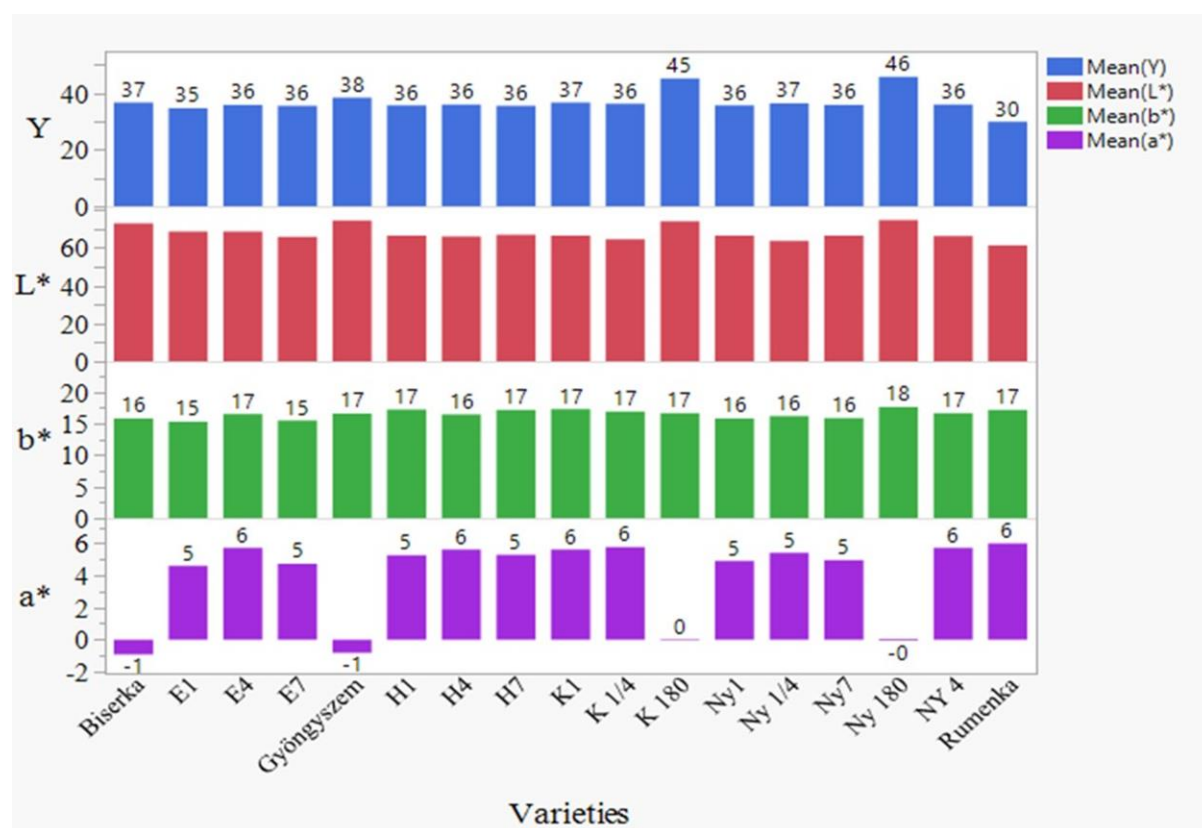


Figure 30. Average of the colour parameters of *S. bicolor* and *P. miliaceum* grain bran fraction attributed to 30s-time unit, $P \leq 0.05$

Furthermore, as an indication of the precision of the colour measurements, the white *S. bicolor* and *P. miliaceum* varieties, such as (Biserka and Gyöngyszem) and Farmsugro180 variety (sourced from Nyíregyháza) as shown in (Figure 29), which were presented negative values (b^*) at blue spectrum, high values of (L^*) >70 (light) and (Y) at the brightness spectrum, as evidence and proof for the light colour (whiteness) of the respective grain milling fractions.

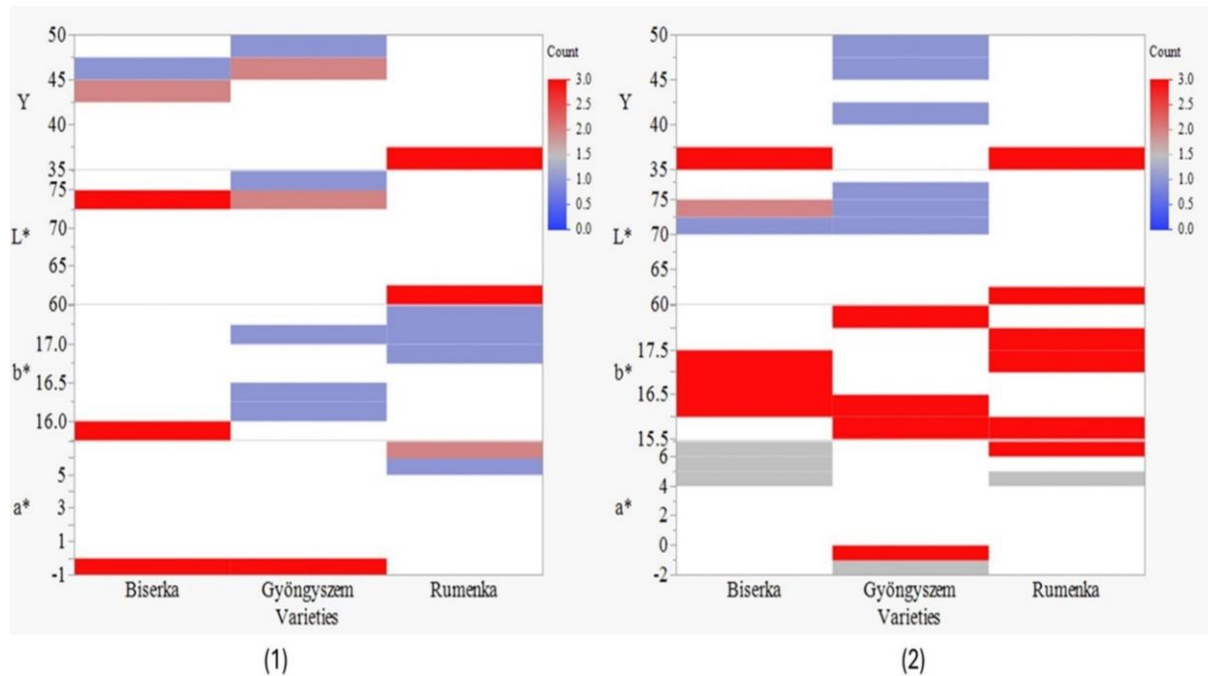


Figure 31. Correlations between the colour parameters of the *P. miliaceum* grain bran fraction attributed to (1) 30s (2) 50s time unit, $P \leq 0.05$

More clarification for the colour profile variation was supported by the resulting bran fraction of *P. miliaceum* from the employed 30s and 80s time units (Figure 27) when the red spectrum (a^*) was concentrated in the case of the Rumenka variety, as the variety showed a strong correlation with a^* parameter within correlation coefficient $R=0.914$; furthermore, the technique of the HFTU process was indicated the reconcentration of the colour darkness when it (Y) spectrum showed a strong correlation between Biserka and Rumenka varieties within correlations coefficient $R= 0.911$ and $R=0.923$ as shown in (Figure 32), with a significance variance of ($P < 0.05$).

On the other hand, the color profile variance of *S. bicolor* grain varieties was investigated and attributed to the employed 30s- and 80s-time units in Figures 24 and 32. While the modification of the sorghum bran fraction fluctuated, however, the displayed relationship (Figure 32) indicated a minor reduction in the spectrum of brightness (Y) and yellow (b^*) in the case of

the Farmsurgro180 variety from Kacarg and Nyíregyháza. The coefficient correlations of $R=0.537$ and $R=0.521$ were reduced to $R=0.419$ and $R=0.402$, respectively.

The detailed finding outcomes of the HFTU were reflected in the mentionable variation of the whole grain (Tannic acid %) and bran fraction (colour spectrum).

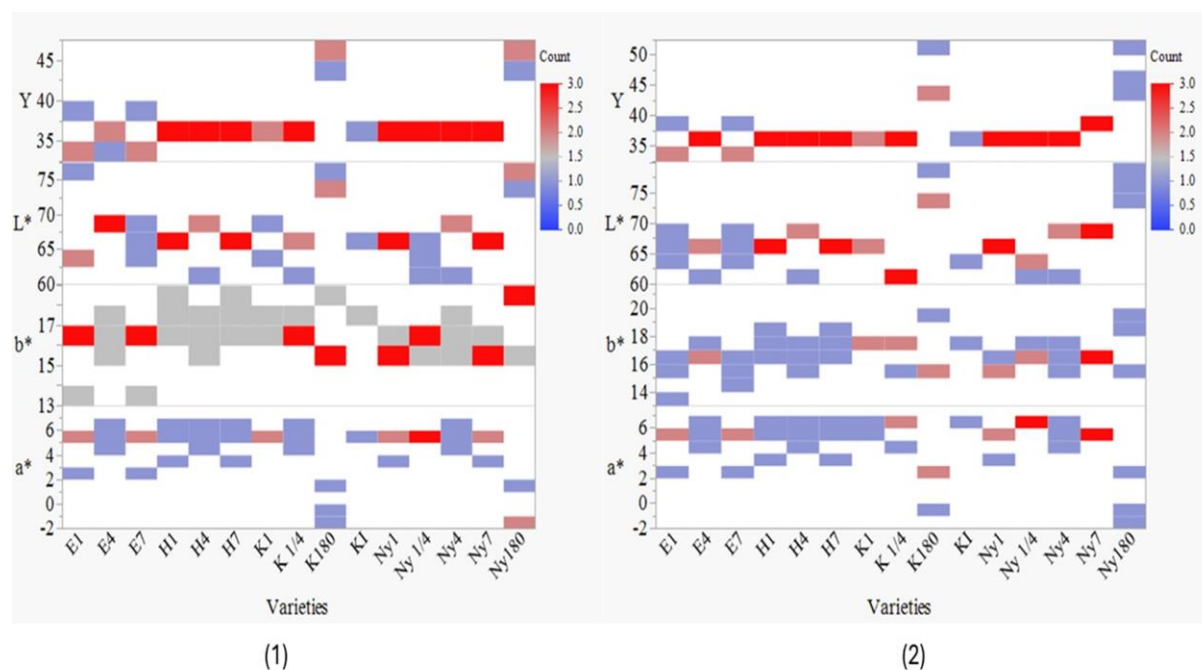


Figure 32. Correlations between the colour parameters of the *S. bicolor* grain bran fraction attributed to (1) 30s (2) 80s-time unit, $P \leq 0.0$

4.5. Results of the consequences of the husking process on nutritional properties of two sorghum races on male sterility inbred lines

The research aimed to evaluate the precision of the HFTU technology by testing the HFTU dehulling approach on two sorghum races inbred lines. The investigation was performed to evaluate and ensure the efficiency of the employed husking process, consistent and uniform grain quality, and high-quality products suitable for human consumption, specifically for sorghum inbred lines. The investigation can contribute to the food industry benefiting from improved quality and uniformity of processed grains. Specifically, the measurement procedure was essential for attaining equitable contributions from two sorghum races in male sterility lines, which include a sterility line and a restorer line. Furthermore, the procedure was performed on a specific cultivar, the Alpha 12 race. The study used the early and late-ripening traits of the sorghum bicolor race and the late-ripening stage of the Kafir race.

4.5.1. Influence of the HFTU process on the dry matter and crude protein

The results demonstrated that the HFTU process affected the dry matter and total protein content. That was evident from the increased protein concentration in the husked products compared to the ground whole grains. For example, the crude protein content varied from 8.0 to 23.0 g/kg in the case of *S. bicolor* race. Simultaneously, no notable variation was identified across the various varieties ($P > 0.05$).

The efficiency of the HFTU process was assessed by measuring the redistribution, reconcentration, and accumulation of protein in the husked product (bran and endosperm (grits)) of different sorghum races at various ripping stages. The results showed statistically significant protein differences ($P < 0.05$). The variation in crude protein percentage was 19.2% based on the ground whole grains/endosperm (grits) and 10.4% based on the whole grains/bran. The endosperm (grits) had the largest protein level, measuring 1.7%, while the bran had a protein value of 0.87%. The study found that 28.9% of the total variations had a greater protein concentration in the endosperm than the bran, ascribed to various ripening phases. Among these varieties, the *S. bicolor* (Alpha 4 race) had the greatest protein content in the endosperm, within 1.5% and 1.2% in the brain, as shown in Appendix 15.

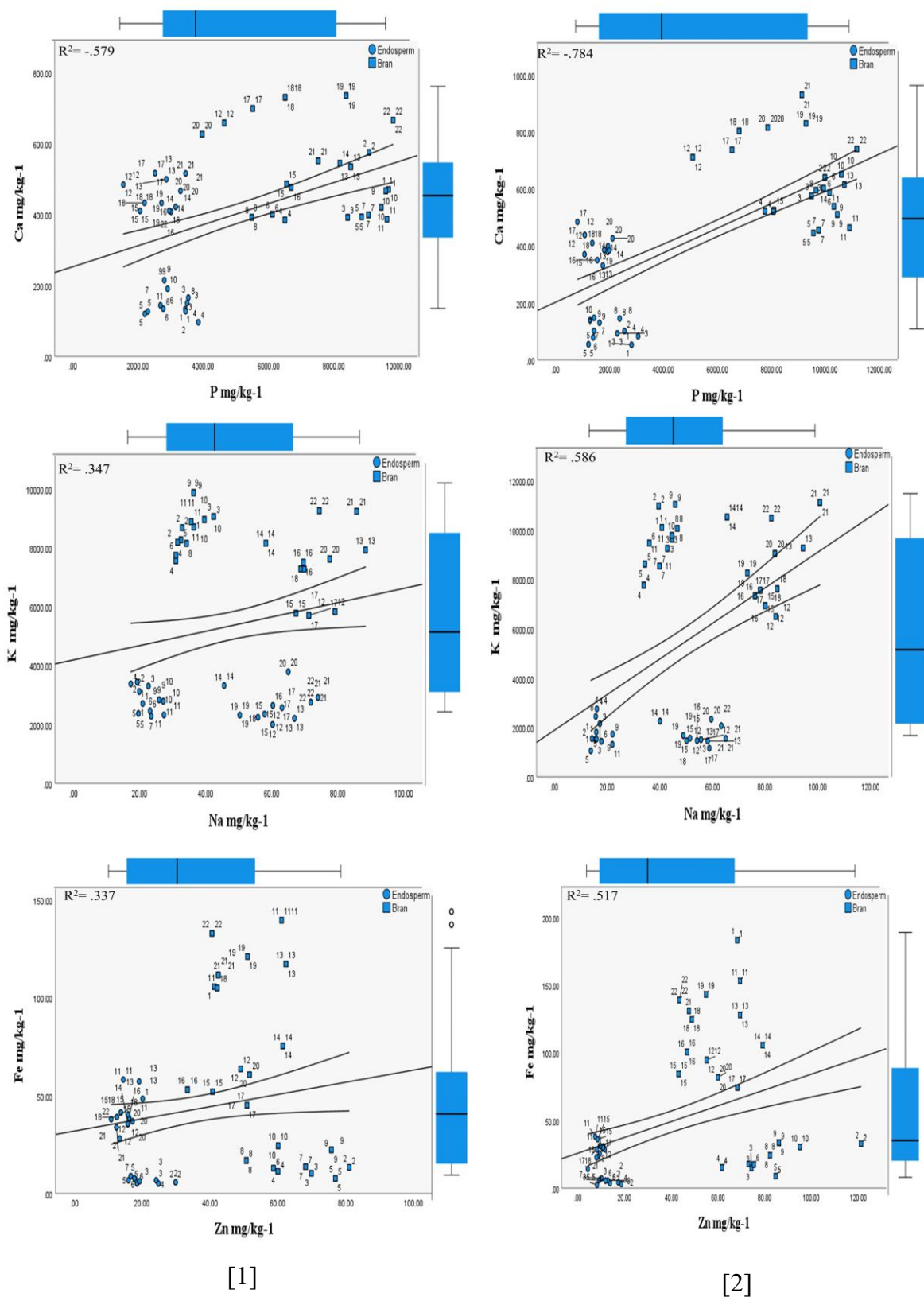
4.5.2. Influence of the (HFTU) process on the macro-mineral (P, K, S, Ca, Mg, and Na)

According to an investigation of the ripping stages impact, the findings revealed significant effects of the HFTU procedure on the concentration of phosphorus (P) in the tested inbred *S. bicolor* race attributed to (early and mid-ripping phases), with $P < 0.05$. The bran had the highest phosphorus (P) mineral concentration at 7985 mg/kg, whereas the whole grains had a lower 3137 mg/kg concentration. The disparity between the entirety of the grains and the bran was 154.6%. The endosperm grits at the early, middle, and late ripping phases showed the lowest accumulation, as seen in Figures 33 (1, 2) and 34 (1, 2). Simultaneously, the bran fluctuated the 30s- and 80s-time units, at 18.1% of the total; more explanation is detailed in Appendix 15 and 17.

The HFTU approach significantly increased the potassium mineral contents in the various varieties, notably in the bran portion. The potassium levels varied from 3160 to 11949 mg/kg of 36.3 mg/kg and 54.4 mg/kg were associated with a duration of 80s time units, with a significance level of ($P < 0.05$). However, the ratio of K: Na was found to be 97:1, compared to 69:1 in the ground (whole grains), as determined from the values shown in Appendix 15 and 17.

4.5.3. Influence of the (HFTU) process on the micromineral (Fe, Zn, Cu, and Mn)

Copper (Cu) mg/kg concentration was acceptable compared to the other mineral contents studied. The average husked product endosperm (grits) and bran concentration varied from 2.8 mg/kg to 10 mg/kg (Appendix 16 and 18). The greatest average concentration, 10 mg/kg, was detected in the bran. On the one hand, the bran to whole grain ratio was found to be 3:1 for the races of *S. bicolor*, with a statistically significant difference ($P < 0.05$). On the other hand, the Kafir race had the highest average within 16 mg/kg, although this difference was not statistically significant ($P > 0.05$).



*Numbers [1] correlation based on 30s-time unit, [2] correlation based on 80s-time unit, the linear correlation analysis was performed based on mean values, with a 95% confidence level

Figure 33. Correlation between the most frequently interacting mineral compositions of the *S. bicolor* race stated by the (HFTU) technique, $P \leq 0.05$.

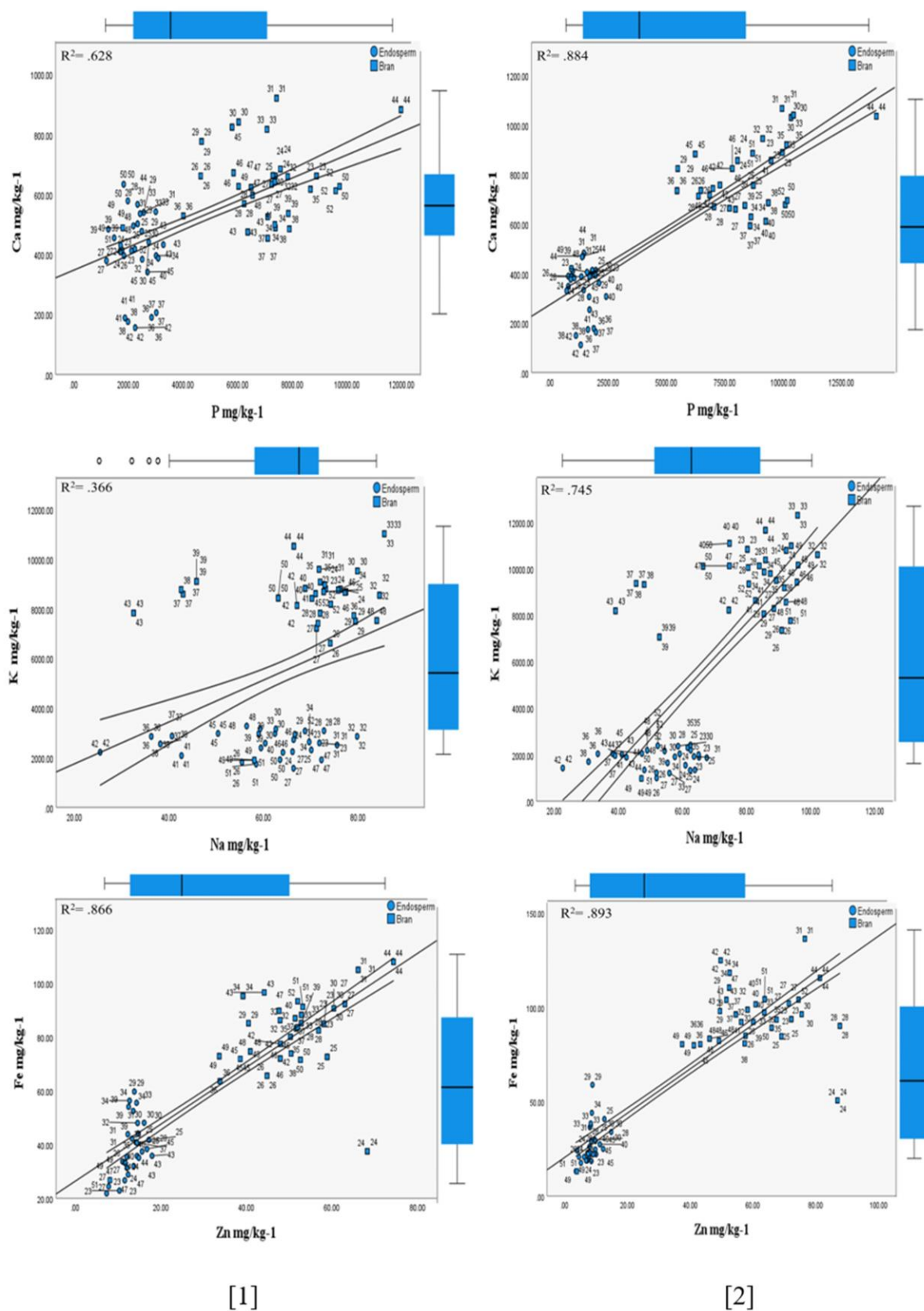
In the *S. bicolor* race, and range of 6977 to 11658 mg/kg in the Kafir race. The Alpha 4 *S. bicolor* variety (early ripening) had the highest average of 9754.7 mg/kg-1, which may be attributable to 80s-time units, as shown in Figures 33 (1, 2) and 34 (1, 2). That was proved in the case of Kafir races. The fluctuation in K mg/kg concentration did not provide a statistically significant result ($P > 0.05$) in the husked grain of the two sorghum races.

The Ca mg/kg content obtained from the Husking Fraction Time Unit (HFTU) procedure is presented in Figures 34 (1, 2) and 35 (1, 2). For *S. bicolor*, the Ca mg/kg contents of the whole grain, endosperm (grits), and bran were measured at 373.6 mg/kg, 268.9 mg/kg, and 566.7 mg/kg, respectively. On the other hand, the Kafir race exhibited mean values of around 494.5 mg/kg, 381.2 mg/kg, and 716.3 mg/kg, respectively.

The data in Appendix 15 and 17 indicated that the levels of Ca mg/kg were affected by the dehulling process and changes in ripping times. We computed the Ca: P ratio to estimate the levels of phytic acids in the tested races, as seen in Figures 34 (1, 2) and 35 (1, 2). The demonstration occurs at 1:15 in the *S. bicolor* race and at 01:11 in the Kafir race.

The study found that the HFTU process had different effects on the Mg mg/kg levels in the sorghum races' whole and dehulled grains, as observed in Table 19. Specifically, the Mg mg/kg concentration was highest at 1657.1 mg/kg after 30s-time units, compared to 1053.4 mg/kg after 80s-time units, as shown in Figure 34 (1, 2). Although there was a noticeable variance in the Mg mg/kg content among the different sorghum races, the statistical analysis did not indicate any significant difference ($P > 0.05$) in the milling quality of the husked fraction. Conversely, the ratio of whole grain to bran was shown to be 5:1.

Determining sodium (Na) mineral content in cereal grains is important for assessing the nutritional value of a healthy diet. The HFTU procedure notably affected sodium (Na) redistribution and reconcentration in husked *S. bicolor* grain races, as shown in Appendix 15 and 17. The analysis revealed a decrease in Na mg/kg in the bran part compared to the endosperm (grits). The *S. bicolor* and Kafir races exhibited mean concentrations of 36.9 mg/kg and 61.8 mg/kg, respectively, throughout a 30s-time unit period (Tables 15 and 16).



*Numbers [1] correlation based on 30s-time unit, [2] correlation based on 80s-time unit, the linear correlation analysis was performed based on mean values, with a 95% confidence level

Figure 34. Correlation between the most frequently interacting mineral compositions of the Kafir race stated by the (HFTU) technique, $P \leq 0.05$.

The findings indicated that the alpha-4 variety (*S. bicolor*) has a notable amount of copper (Cu) in the endosperm (grits), specifically within the range of 10 mg/kg. That observation contrasted the results seen in the middle- and late-ripening-stage varieties.

The Husking Fraction Time unit (HFTU) process positively impacted the Fe mg/kg contents of all the sorghum inbred line races studied. However, the effect of the HFTU process varied between the endosperm (grits) and bran, particularly among the *S. bicolor* race, as shown in Tables 16 and Appendix 15. The variation was statistically significant, with a significance value of ($P < 0.05$). The results indicated that the male sterility line and the ripening phases influenced iron mineral nutrient levels. For example, in the case of *S. bicolor*, the Alpha 12 variety had the highest Fe mg/kg concentration, averaging approximately 147.0 mg/kg (Appendix 15). On the other hand, the Fe mg/kg level in the endosperm compared to the bran decreased by 4%, 7%, and 2% in the Alpha 2, Alpha 4, and Alpha 1 races, respectively.

The results showed that the Zn mg/kg levels were increased after applying the HFTU technique, as shown in Appendix 16 and 18. Moreover, this was shown by a higher concentration of zinc minerals in the husked grain (bran) compared to whole grains (ground), with average levels of 23.3 mg/kg and 58.7 mg/kg, respectively. The results are shown in Tables 16 and 36.

According to Figure 25 (1, 2), the 30s- and 80s-time units showed a range of variance, with average values of 53.1 mg/kg and 64.4 mg/kg, respectively, and a ratio of 9.64%.

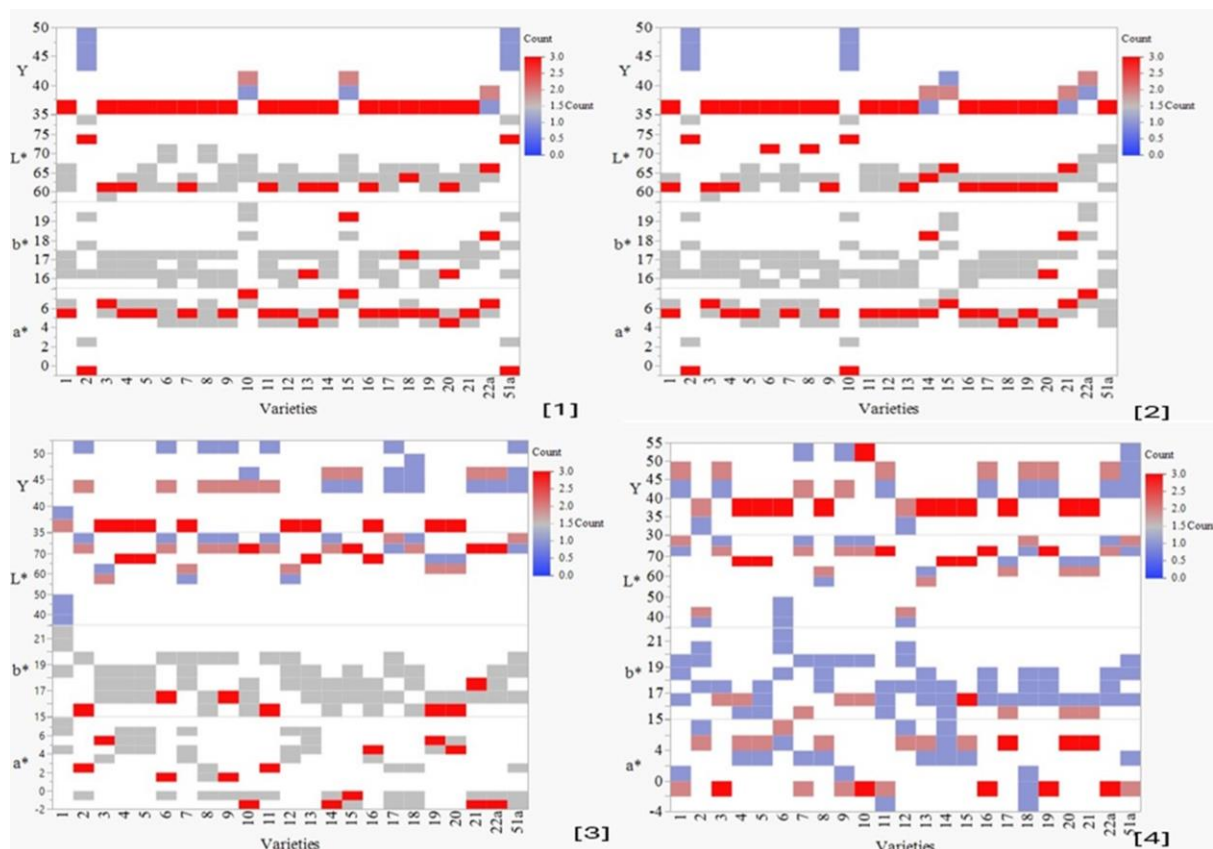
Furthermore, Figures 33 (1, 2) and 34 (1, 2). indicated that the 80s-time unit significantly affected iron and zinc concentrations in different sorghum races (*S. bicolor* and Kafir) were Figures (25 (1,2) and 26 (1,2)). These figures also revealed a strong correlation between the iron (Fe) and zinc (Zn) mg/kg concentration, with correlation coefficients of $R = 0.517$ and $R = 0.893$, respectively.

The impact of the HFTU process on the Mn mg/kg concentration (Appendix 16 and 18) was observed through a significant increase in Mn mg/kg content in the husked products, with an average of 34.6 mg/kg in the bran, compared to 17.7 mg/kg in the whole grain (ground). These differences were attributed to the genetic variation of the sorghum race. Additionally, a variation ratio of 10.13% was observed between the 80s- and 30s-time units, with a significance value of ($P < 0.05$), as detailed in Figures (25 (1,2) and 26 (1,2)).

4.5.4. Influence of the (HFTU) process on the Colour properties implied from 30s- and 80s-time units

Based on the findings of the Husking Fraction Time Unit (HFTU) technique, the colour properties of the different varieties were judged to change between the 30s- and 80s-time units, as seen in Figure 34 (1,2). A significance level of $P < 0.05$ demonstrated that the observed changes were statistically significant. The endosperm (grits) colour characteristics showed a positive range starting at 30s-time units.

The variations in the colour of the bran, which took place throughout 80s-time units, did not affect the varieties with brown pericarp colour (Appendix 15 to 18) throughout the middle and late stages of ripping. The fact that the (a^*) parameter's (-2) negative value (which indicates redness) confirmed this. In addition, the Husking Fraction Time Unit (HFTU) procedure, which lasted for 80s-time units, resulted in a reduction in darkness (L^*) and brightness (Y). The range of darkness spanned from 40 to 70, whereas the range of brightness spanned from 35 to 50.



The letter refers to [1]: endosperm colour properties in case of the 30s, [2]: bran colour properties in case of 30s, [3]: endosperm colour properties in case of the 80s, [4]: bran colour properties in case of 80s, 22a: alpha 22variety (Kafir races), and 51a: alpha 51variety (Kafir races).

Figure. 35. The colour profile of the analyzed inbred line varieties is based on endosperm (grits) and bran., $P \leq 0.05$.

5. Discussion

The current study evaluated the nutritional properties of alternative cereal grains in the Mediterranean regions. Based on a comparison approach attributed to three different collections, the investigations revealed significant variations and concluded with relevant scientific results. These findings, which fulfilled the highlighted objectives, addressed the utmost issues concerning promoting *S. bicolor* and *P. miliaceum* grains for human dietary consumption. The research also proved the investigation hypothesis by discovering the factors that can affect the nutritional composition of both grains, thereby supporting the outlined objectives. Each relevant finding was explained and clarified, highlighting the practical implications and applicability of the study's conclusions. Moreover, measured variables were assessed based on the truth of the study hypothesis $P \leq 0.05$.

The research project objectives are outlined in Chapter 1.2, and the corresponding answers:

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.

The study objective 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 respective region, such as winter wheat and oat, compared to potential staple crops, such as *S. bicolor* and *P. miliaceum* 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. miliceum*) cultivated under the N fertilizer controlling, particularly in the sites

where 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 $\times$ 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. miliceum*, 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 Ca^{2+} ions from the soil particles. Consequently, sodium (Na) and calcium (Ca) levels in *S. bicolor* grains decreased in loam clay and sandy soil.

Generally, the examined grain varieties showed an acceptable sodium (Na) level mineral when the range of 11.5 to 54.38 mg/kg was reported in the sorghum grains (Tasie & Gebreyes, 2020), while the range of 86 mg/kg in whole grain of *P. miliaceum* (Bagdi et al., 2011).

- 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 (PO_4^{3-}) after the hydrolysis reaction. The *S. bicolor* grains have a good capacity for nutrient absorption, as discussed in a previous report (Barlóg, 2023). The authors investigated many factors that affect the efficiency of fertilizer consumption, including soil type, crop type, and agricultural practice for fertilizer applications. They also emphasized the need for soil testing to enhance the effectiveness of nitrogen management planning and controlled factors affecting nutrient viability (Khalfalla et al., 2024).

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 experiments for sorghum crops based on the two soil types, Karcag (loam clay) and Nyíregyháza (sandy), among common regions for sorghum cultivation in Hungary.

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. milaiceum* as alternative cereal grains based on the levels of N, K, P, S, Fe, Cu, Zn, Na, and Mn in the diverse varieties as was shown in (Tables Appendix 4 to 14), 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 facilitate 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 (Tables 6 and 8), 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. miliaceum* 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. To confirm the precision of Mn mg/kg among the respective varieties, we compared the findings with the literature, and the results were linked to (Stepien et al., 2019). The study showed that winter wheat has a high Mn mg/kg level, which can be attributed to N fertilizer application.

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.

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.

Features of the nutritional Composition:

Sorghum: Sorghum from different regions may have varying hull thickness and nutrient distribution (Table 19). Based on the HFTU process, a 30-second dehulling might preserve total dietary fiber, while an 80-second dehulling enhances the bioavailability of iron, zinc, and proteins, according to Figure 24 (1,2).

Millet: The diverse *P. miliaceum* varieties may respond differently to the dehulling process. According to the revealed findings, a 30-second dehulling might have kept more nutrient content intact, while a 50-second process increased the availability of total dietary fiber and proteins, enhancing overall macro-mineral nutrient reconcentration and redistribution compared to micromineral; the mentionable reduction was observed in the bran fraction of the *P. miliaceum*.

Varietal and Regional Differences: The variation of cereal grain sources can provide unique characteristics such as various nutritional properties, different adaptation mechanisms for the dehulling process, and colour stability. In contrast, evaluation of the dehulling resistance attributed to varieties from one region might have a tougher hull, requiring a longer dehulling time for significant nutrient enhancement, as indicated by the protein variation ratios implied from the whole grain/endosperm and whole grain/bran instance of *P. miliaceum*, which was observed between 17.7 % and 27.8 %, contrary to variation of 26.6% that recorded sorghum grain varieties from various regions, which resulted from bran/endosperm data set, the result of the fractions presented separately in Table 20.

In contrast, a prior study conducted by (Bagdi et al., 2011) found that the crude protein content in the *P. miliaceum* after the decortication process ranged from 11.0% to 14.8% per 100 g, which was lower than the nitrogen (N) content of 21.6 % in husked *P. miliaceum* (obtained from a retail store), as reported in the current study. The mentioned comparison indicates the enhancement of Hungarian cereal products over time.

All the findings indicated that by adjusting the dehulling time, we can optimize nutrient retention and variability, thereby enhancing the nutritional value of these grains for human consumption. These findings have profound implications for fortified whole grains (with N fertilizer), un-fortified whole grains (without N fertilizer), and processed grains (fractions)

nutritional value variations, as discussed and explained in Figures (35 to 37). It can facilitate the understanding of promoting the nutritional value that fulfills human dietary supplements. We benefited from the technique, which enhanced the concentration of specific nutrients such as crude protein and iron (Fe) minerals and reduced sodium (Na) minerals, as was noticed in the AS1 2021 variety from Nyíregyháza; in contrast, it was difficult to distinguish these nutritional properties in the whole grain products, in providing specific nutrient composition making them a healthier choice for certain dietary groups, as were detailed in Table 1. the findings were aligned to (Kołodziejczyk et al., 2018), according to the study's findings, the scientists recommended a new sufficient milling process to maintain the nutritional contents in the dehulled cereal grains. More described in (Figures 24 (1,2) to 27(1,2)).

According to the investigation's findings, the objective outcomes can be summarized in several points. For example, milling fractions can be engineered to improve the nutritional value of various products, including pasta, bread, and noodles, thereby increasing their appeal to health-conscious consumers. Additionally, milling fractions may contain antioxidant compounds that support the revealed nutritional value of the examined nutrient components, making them a beneficial diet for preventing uncommunicable diseases attributed to deficiencies in the dietary supplements' recommended values (Table 1), as investigated by the research project. An instance of the revealed dietary fiber content in *P. miliaceum*, ranging from 92.0 g/kg to 70.1 g/kg, can enhance feelings of fullness, facilitate digestion, and maintain a healthy gastrointestinal system according to (Balli et al., 2023).

The objectives are outlined in Chapter 1.3, and the corresponding answers:

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).

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.

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 specific traits to each variety and region.

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 have 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 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.

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 characteristics 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 published by (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.

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.

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), according to explanations in Figures (36 to 38). The process can produce 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 (36 (1,2,3) to 38 (1,2,3)). 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.

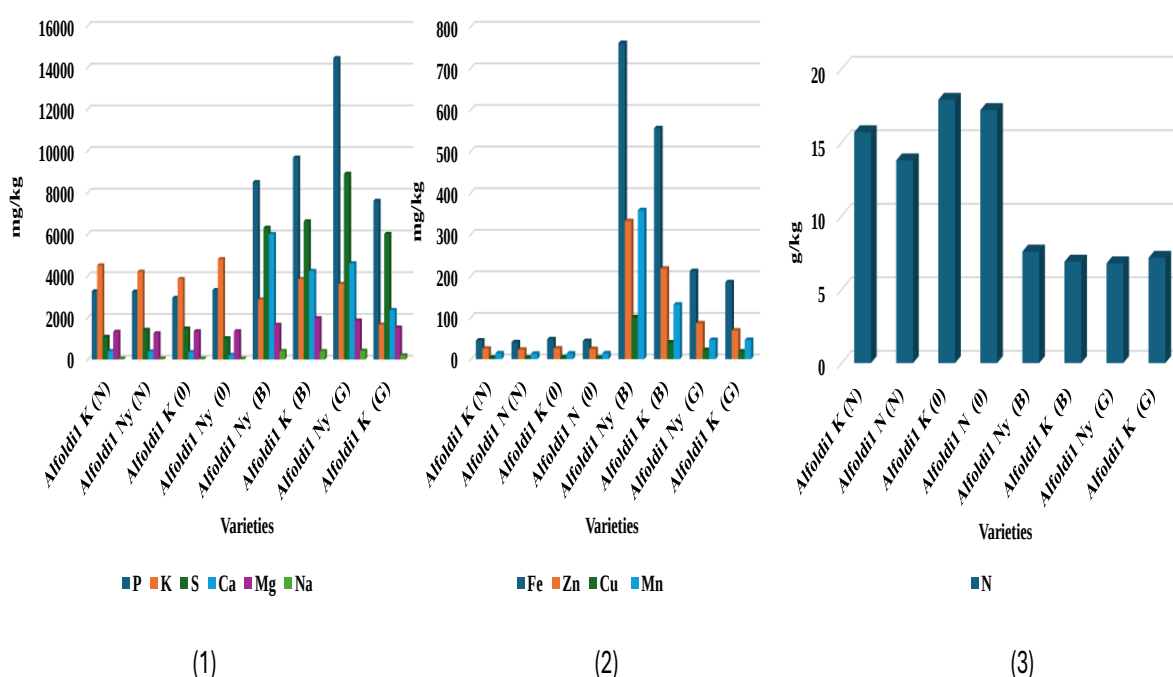


Figure 36. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Alföldi 1 (red sorghum variety) based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

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 nutritional 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 (Table 14 and Figure 24(1,2)). The result was evidenced by the responsiveness of the Alföldi 1 variety for the husking process, as described in Figure 37(1,2,3) with a significance value of ($P < 0.05$). Contrary to K mg/kg concentrations, when the lowest average of K mg/kg was noticed among the Alföldi 1 variety sourced from the Karcag and Nyíregyháza regions, with an average of 1689 mg/kg and 1667 mg/kg, respectively (Figure 29).

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.

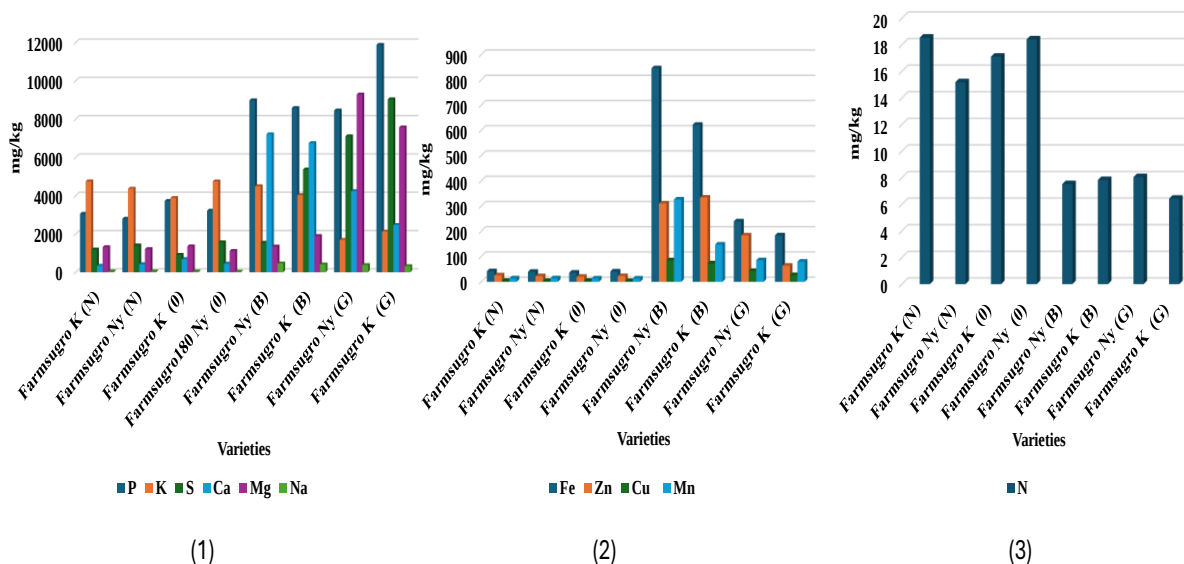


Figure 37. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Farmsugro180 (white sorghum variety) based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

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).

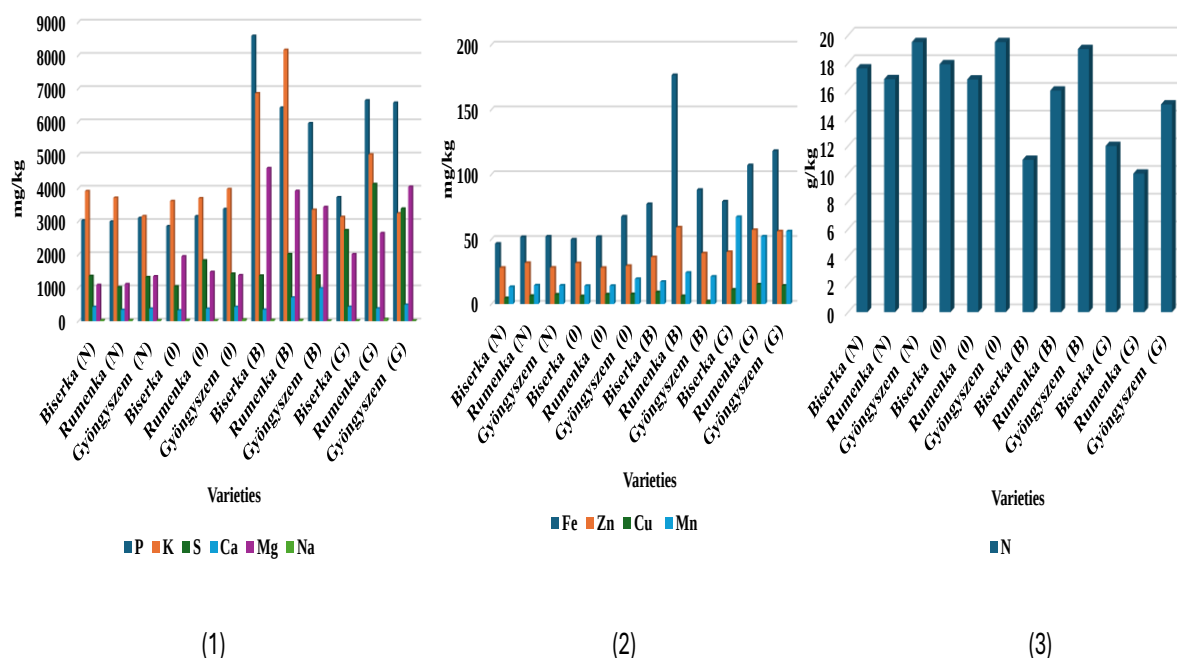


Figure 38. Average of (1) macro-mineral, (2) micromineral, (3) crude protein contents in Biserka, Rumenka, and Gyöngyszem based on variety (N) treated with N fertilizer, (0) without N fertilizer, (B) bran fraction, (G) grits fraction, $P \leq 0.05$

We evaluated the *P. miliaceum* nutritional characteristics attributed to various treatment circumstances Figure 38 (1,2,3), 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 (Table 20) of the dehulled grains compared to the presented data in Appendix 7 of the whole grains (ground), 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 (Table 26).

This 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 (Tables 20) compared to similar dehulled sorghum grain varieties from the different three regions in Hungary (Appendix 1).

The findings, which are presented in Appendix 7 and Figure 27(1,2), show 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 22 and 23.

Table 22. 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 19).

Table 23. 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 22 and 23.

To update the data on analyzed Hungarian cereal grain varieties and evaluate the significant findings of their nutritional profiles compared to worldwide literature results.

The research project's results provided good insight into the advancement of *S. bicolor* and *P. miliaceum* for human consumption in the region adapted for cultivation, presenting global concerns about potential staple cereal grains in Eastern Europe, particularly Hungary.

On the other hand, the project investigation offered a unique update about National (Hungarian) advancement in *S. bicolor* and *P. miliaceum* breeding and production based on a diverse collection sourced from the common site for millet production. The results demonstrated improvements in agricultural practices based on the findings of various cereal grains under N fertilizer circumstances, which lined up with (Jóvér et al., 2018; Höhn & Rötter, 2014), the decortication process revealed a rich nutritional content, as shown by comparing the recent results of previously published findings (Langó et al., 2018; Torbica et al., 2021).

The study results indicated that mineral nutrient levels, such as those in Hungarian *S. bicolor* and *P. miliaceum* grain varieties, fell within an acceptable range, as shown in Table 1.

The objectives are outlined in Chapter 1.4, and the corresponding answers

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 kafir race, and how the innovative technique can influence the nutritional properties based on various maturity stages.

The occurrence of male sterility in sorghum, often used in hybrid breeding initiatives, may significantly impact different processing methods, such as the HFTU process, considerably influencing the nutritional quality of sorghum. Dehulling can reduce the fiber, vitamins, and minerals from the outer layers, while milling eliminates nutrient-rich cereal and seed, resulting in a starchy endosperm. By comprehending these processes, strategies can be devised to preserve the required nutritional value of the genetic characteristics in the male sterility line of the examined sorghum races (*S. bicolor* and Kafir), considering the revealed nutrient content variations.

The last stage of the project investigations involved assessing the effectiveness of the HFTU process on two sorghum races in a male sterility inbred line, involving 51 varying samples of the *S. bicolor* and Kafir races.

The findings showed significant effects of the Husking Fraction Time Unit (HFTU) approach. These effects were shown when the dry matter % decreased in the husked products, notably the endosperm (grits). Conversely, the protein proportion exhibited a 14.2% alteration compared to the bran to endosperm (grits). The observed variations of P mg/kg, K mg/kg, S mg/kg, Fe mg/kg, and Zn mg/kg were within the ranges of 18.10%, 12.29%, 13.43%, 22.18%, and 21.36%, respectively, in case of the 80s and 30s variations, as detailed in Figure 33 (1,2). Future research recommendations include evaluating protein content qualities and performing rheological property tests to optimize the nutritional profile of sorghum cultivars utilizing the HFTU approach.

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 (Appendix 17), 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 research findings, the Alpha 4 race of sorghum race demonstrated that its protein content correlated with an iron concentration.

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, as shown in Figure 33 (1,2), which makes it an advantageous candidate for potential product advancement.

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.

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 content in (Table 22) was 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.

6. 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 the examined cereal 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.

7. 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 reconcentrates 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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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., Győri, 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.
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List of other publications

Foreign language international book chapters (1)

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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.
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Appendix

Appendix 1. Collection of commercial sorghum grain varieties attributed to soil type in the production site (region)

Variety	Production site (region)	Soil type	Grain colour
KWS Lupus	Murony	Chernozem	Brown
KWS Nemesis	Murony	Chernozem	Brown
GK Illoa	GK	Loam	Brown
GK Erzsébet	GK	Loam	Brown
GK Emese	GK	Loam	
Alföldi 1	Szeged	Loam	Brown
Farmsugro180	Szeged	Loam	White
Alföldi 1	Nyíregyháza	Sandy	Brown
Farmsugro180	Nyíregyháza	Sandy	White
Alföldi 1	Kacarg	Loam	Brown
Farmsugro180	Kacarg	Loam	White
ES Föehn	Nyíregyháza	Sandy	Red
Gustav	Nyíregyháza	Sandy	Brown
ES Alize	Nyíregyháza	Sandy	Brown
ES Monsoon	Nyíregyháza	Sandy	Brown
ES Shamal	Nyíregyháza	Sandy	Brown
KWS Nemesis	Nyíregyháza	Sandy	Brown
AS1 2021 IMI	Nyíregyháza	Sandy	Brown
AS2 2021	Nyíregyháza	Sandy	Brown
Alföldi 1	Nyíregyháza	Sandy	Brown
Farmsugro180	Nyíregyháza	Sandy	Brown
ES Föehn	Esztár	Luvisol	Red
Gustav	Esztár	Luvisol	Brown
ES Alize	Esztár	Luvisol	Brown
ES Monsoon	Esztár	Luvisol	Brown
ES Shamal	Esztár	Luvisol	Brown
KWS Nemesis	Esztár	Luvisol	Brown
AS1 2021 IMI	Esztár	Luvisol	Brown
AS2 2021	Esztár	Luvisol	Brown
ES Föehn	Hortobágy	Humic gley	Red
Gustav	Hortobágy	Humic gley	Brown

ES Alize	Hortobágy	Humic gley	Brown
ES Monsoon	Hortobágy	Humic gley	Brown
ES Shamal	Hortobágy	Humic gley	Brown
KWS Nemesis	Hortobágy	Humic gley	Brown
AS1 2021 IMI	Hortobágy	Humic gley	Brown
AS2 2021	Hortobágy	Humic gley	Brown
Biserka	Nyíregyháza	Sandy	Yellowish
Gyöngyszem	Nyíregyháza	Sandy	White
Rumenka	Nyíregyháza	Sandy	Red
Millet flour 1	Retail store shop	-	Yellow
Husked millet2	Retail store shop	-	Yellow
Sorghum flour	Retail store shop	-	White
Husked sorghum	Retail store shop	-	White

Appendix 2. Collection of *S. bicolor* race inbred line and their distinct characteristics

Identifier	Race	Line type	Colour of pericarp	Ripping Time	Soil type
Alpha 1	Bicolor	A (male sterile mother)	brown	Middle	Loam clay
Alpha 2	Bicolor	A (male sterile mother)	white	Middle	Loam clay
Alpha 3	Bicolor	A (male sterile mother)	brown	Middle	Loam clay
Alpha 4	Bicolor	A (male sterile mother)	brown	Early	Loam clay
Alpha 5	Bicolor	A (male sterile mother)	brown	Middle	Loam clay
Alpha 6	Bicolor	A (male sterile mother)	white	Middle	Loam clay
Alpha 7	Bicolor	A (male sterile mother)	brown	Late	Loam clay
Alpha 8	Bicolor	A (male sterile mother)	white	Middle	Loam clay
Alpha 9	Bicolor	A (male sterile mother)	white	Middle	Loam clay
Alpha 10	Bicolor	A (male sterile mother)	white	Late	Loam clay
Alpha 11	Bicolor	A (male sterile mother)	brown	Middle	Loam clay
Alpha12*	Bicolor	B (father maintaining sterility)	brown	Middle	Loam clay
Alpha 13	Bicolor	A (male sterile mother)	brown	Late	Loam clay
Alpha 14	Bicolor	R (fertility restoring father)	white	Middle	Loam clay
Alpha 15	Bicolor	R (fertility restoring father)	white	Middle	Loam clay
Alpha 16	Bicolor	R (fertility restoring father)	brown	Middle	Loam clay
Alpha 17	Bicolor	R (fertility restoring father)	white	Middle	Loam clay
Alpha 18	Bicolor	R (fertility restoring father)	white	Middle	Loam clay
Alpha 19	Bicolor	R (fertility restoring father)	brown	Middle	Loam clay
Alpha 20	Bicolor	R (fertility restoring father)	brown	Middle	Loam clay
Alpha 21	Bicolor	R (fertility restoring father)	white	Middle	Loam clay

Appendix 3. Collection of *Kafir* race inbred line and their distinct characteristics

Identifier	Race	Line type	Colour of pericarp	Ripping Time	Soil type
Alpha 22	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 23	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 24	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 25	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 26	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 27	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 28	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 29	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 30	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 31	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 32	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 33	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 34	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 35	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 36	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 37	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 38	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 39	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 40	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 41	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 42	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 43	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 45	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 44	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 45	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 46	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 47	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 48	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 50	Kafir	R (fertility restoring father)	white	Late	Loam clay
Alpha 51	Kafir	R (fertility restoring father)	white	Late	Loam clay

Appendix 4. Descriptive statistical analysis of phosphorus (P) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	4661.4	199.4	4380.9	4941.8
E1	3909.0	1690.3	2703.8	5114.2
Ny1	3576.9	199.5	3435.9	3718.0
H2	5185.6	1240.3	3756.7	5985.0
E2	5153.7	112.5	6351.8	4119.5
Ny2	4875.5	1091.9	3727.7	5901.3
H3	5693.7	940.6	4816.6	6687.2
E3	5428.6	962.1	4317.5	5989.0
Ny3	3887.6	848.4	3323.2	4863.3
H4	5385.3	1106.6	5180.4	5590.2
E4	5824.7	289.8	5042.2	6607.2
Ny4	5098.1	655.4	4634.6	5561.5
H5	5024.0	1002.5	4615.5	5994.2
E5	5707.8	257.5	5453.1	5968.0
Ny5	4842.6	1199.3	3590.7	5981.4
H6	3322.7	99.3	3312.3	3329.8
E6	5405.4	569.5	4785.4	5905.3
Ny6	5571.8	181.8	5374.3	5732.3
H7	4301.3	1279.3	3106.1	5496.5
E7	4468.8	104.3	3564.2	5373.4
Ny7	4605.0	104.3	4283.1	4926.9
H8	4500.2	1129.4	4111.5	4888.9
E8	4282.6	1803.8	2580.1	5985.3
Ny8	4752.9	676.0	3975	5197.5
K 1/4	2946.2	287.0	2656.7	3231.1
Ny 1/4	3320.9	165.6	3130.0	3427.1
Sz 1/4	3171.7	247.4	3020.4	3457.3
K 180	3722.0	1389.5	2914.3	5326.5
Ny 180	3212.0	222.5	3083.5	3469.0
Sz180	3113.5	175.9	2997.0	3316.0
GK Emese	2849.4	8.0	2844.7	2858.6

GK Illona	2996.3	241.9	2060.0	2481.7
GK Erzsébet	2339.7	241.9	2481.7	2060.0
KWS Nemesis	3528.0	7.2	3520.0	3534.0
KWS Lupus	3814.0	3.6	3810.0	3817.0
Biserka	2857.7	13.1	2848.4	2866.9
Rumenka	3157.6	142.8	3155.9	3159.2
Gyöngyszem	3374.6	370.0	3250.5	3498.7
Millet flour*	2625.9	5.0	2622.2	2633.2
Husked millet*	2980.9	9.1	2969.4	2989.9
Sorghum flour*	3317.5	17.1	3297.9	3338.5
Husked sorghum*	3521.4	6.4	3512.9	3525.7

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products sourced from the retail store

Appendix 5. Descriptive statistical analysis of potassium (K) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	6305.9	981.0	5612.2	6999.6
E1	6226.4	921.1	5575.1	6877.8
Ny1	6305.9	981.1	5612.2	6999.6
H2	6307.7	1140.8	5596.3	7623.5
E2	6468.4	208.1	6268.4	6683.4
Ny2	7053.2	445.2	6554.1	7409.4
H3	5975.5	1721.1	3989.3	7026.0
E3	6547.5	364.1	6268.4	6959.4
Ny3	6276.6	658.2	5662.6	6971.7
H4	6353.1	359.5	5396.4	6911.3
E4	6001.8	1071.2	5396.4	6607.3
Ny4	6133.2	449.4	5815.4	6450.9
H5	6117.05	328.2	5814.8	6419.3
E5	6190.9	252.6	5890.8	6490.9
Ny5	5870.8	253.3	5589.0	6079.6
H6	5682.2	611.8	5288.3	6387.1
E6	6431.9	471.4	5952.4	6894.8
Ny6	5896.1	252.6	5606.9	6073.7
H7	5327.8	1255.9	4648.0	6007.6
E7	5444.5	1255.9	4556.5	6332.6
Ny7	5719.9	420.6	5422.5	6017.4
H8	7052.3	54.8	7124.9	7039.5
E8	6777.8	495.7	2573.2	5779.9
Ny8	6224.8	564.0	5719.1	6833.1
K 1/4	4590.3	1756.1	5891.2	5779.9
Ny 1/4	4808.1	1722.1	4799.8	4818.3
Sz 1/4	5129.7	742.1	4275.9	5620.3
K 180	3875.5	623.6	4674.4	4822.6
Ny 180	4740.1	0.9	4739.2	4741.0
Sz180	5324.1	4.1	5319.3	5240.5
GK Emese	4948.6	496.8	4375.0	5240.5

GK Illona	5082.5	45.7	5030.0	5113.5
GK Erzsébet	4560.7	354.6	4350.6	4970.2
KWS Nemesis	2457.3	13.5	2444.0	2471.0
KWS Lupus	2928.0	25.0	2904.0	2954.0
Biserka	3614.3	3.7	3611.6	3616.9
Rumenka	3697.8	618.3	3695.7	3699.9
Gyöngyszem	3973.7	1121.6	3933.9	4013.4
Millet flour*	3521.1	9.1	3510.1	3532.6
Husked millet*	6391.1	190.1	6224.1	6656.1
Sorghum flour*	5538.4	4.9	5532.2	5541.8
Husked sorghum*	5846.4	12.1	5829.2	5855.7

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products sourced from the retail store

Appendix 6. Descriptive statistical analysis of sulphur (S) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	997.9	26.5	979.1	1016.7
E1	1902.7	26.5	1889.2	1916.2
Ny1	965.7	147.8	951.5	979.9
H2	1046.9	61.2	1008.1	1117.1
E2	1046.9	61.2	1008.1	1117.2
Ny2	961.2	135.3	881.6	1117.5
H3	1038.5	20.6	1015.1	1052.4
E3	1036.9	23.5	1010.1	1054.2
Ny3	974.6	51.2	944.1	1033.7
H4	1080.1	445.2	1066.8	1093.4
E4	1237.4	18.7	922.5	1552.2
Ny4	1832.3	48.3	1798.17	1866.4
H5	1096.2	1.5	1095.3	1098.0
E5	1039.8	48.4	1010.2	1095.7
Ny5	960.7	13.7	944.8	969.3
H6	1420.7	45.8	1310.1	1531.2
E6	1090.2	45.8	1081.2	1099.1
Ny6	2316.9	1168.8	967.3	3007.8
H7	1832.8	233.2	430.5	1997.7
E7	994.685	21.9	979.2	1010.2
Ny7	1190.8	294.6	982.5	1399.2
H8	1267.6	492.4	917.9	1830.7
E8	144.9	448.3	954.1	1833.1
Ny8	1127.5	361.9	917.6	1545.4
K 1/4	1479.0	107.4	1377.1	1591.4
Ny 1/4	1010.4	1.5	1008.6	1010.3
Sz 1/4	1180.5	122.6	1087.1	1319.4
K 180	907.9	478.4	360.2	1651.6
Ny 180	1562.3	154.7	1383.6	1651.6
Sz180	1027.5	0.4	1024.3	1030.7
GK Emese	1233.9	271.1	1037.8	1429.9
GK Illona	1304.3	287.8	1054.6	1554

GK Erzsébet	1036.7	50.2	1006.8	1094.4
KWS Nemesis	1151.3	5.5	1146.0	1157.0
KWS Lupus	1282.0	3.6	1278.0	1285.0
Biserka	1044.9	5.6	1040.9	1048.9
Rumenka	1825.9	214.5	1674.2	1977.6
Gyöngyszem	1426.3	26.3	1415.3	1437.3
Millet flour*	1534.2	2.6	290.9	1536.1
Husked millet*	1309.6	2.6	1307.5	1311.2
Sorghum flour*	1025.2	4.6	1022.4	1030.1
Husked sorghum*	1129.5	1.6	1128.1	1130.9

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products sourced from the retail store

Appendix7. Descriptive statistical analysis of calcium (Ca) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	514.3	6.6	413.5	518.9
E1	494.2	119.7	409.5	578.9
Ny1	514.2	6.6	509.5	518.9
H2	622	170.5	425.1	720.5
E2	602.4	15.4	585.1	614.5
Ny2	400.5	159.9	308.2	584.8
H3	644.6	82.7	555.1	718.4
E3	630.2	22.5	614.5	656.1
Ny3	387.5	137.1	308.2	545.8
H4	571.8	117.8	488.5	655.2
E4	505.3	278.6	308.3	702.4
Ny4	623.5	47.6	589.8	657.1
H5	546.1	99.4	487.1	660.9
E5	503.6	126.0	430.4	649.2
Ny5	553.3	6.4	545.8	557.4
H6	489.6	2.1	487.8	492.0
E6	617.8	159.9	433.1	710.3
Ny6	579.6	17.9	590.9	558.9
H7	503.2	137.4	384.5	575.9
E7	481.7	102.0	384.5	578.9
Ny7	383.2	102	230.5	535.9
H8	504.2	62.6	437.5	561.8
E8	380.9	82.0	296.0	480.9
Ny8	504.5	141.1	465.6	543.5
K 1/4	352.6	67.7	280.3	414.5
Ny 1/4	216.7	0.6	215.8	217.2
Sz 1/4	328.7	24.1	314.2	356.6
K 180	686.1	240.8	1161.9	398.9
Ny 180	446.4	5.6	439.8	449.7
Sz180	358.7	2.4	355.3	360.1
GK Emese	345.5	99.7	246.5	446.0
GK Illona	368.5	100.7	281	456

GK Erzsébet	519.8	69.6	450.3	589.5
KWS Nemesis	860.6	1.2	860	862.0
KWS Lupus	905.3	5.8	901	912.0
Biserka	322.1	0.1	322	322.3
Rumenka	372.4	12.1	366.8	378.2
Gyöngyszem	428.1	8.0	386.1	470.3
Millet flour*	292.8	1.7	366.8	295.1
Husked millet*	175.1	0.7	174.4	176.0
Sorghum flour*	717.9	3.2	714.6	722.1
Husked sorghum*	211.6	0.3	212	211.5

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 8. Descriptive statistical analysis of magnesium (Mg) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	1373.0	277.2	1177.1	1569.1
E1	1454.0	189.5	1320.0	1588.0
Ny1	1373.0	277.2	1177.0	1569.1
H2	1290.7	181.6	1131.7	1449.7
E2	1239.9	224.1	1015.7	1463.9
Ny2	1463.6	142.6	1376.7	1628.2
H3	1398.8	235	1537.5	1127.5
E3	1568.8	47.3	1515.1	1604.5
Ny3	1387.4	87.6	1376.9	1394.9
H4	1472.0	258.8	1289.0	1655.1
E4	1381.5	129.5	1290.0	1473.1
Ny4	1526.5	51.7	1490.1	1563.1
H5	1464.9	36.0	1430.4	1502.4
E5	1486.9	125.8	1397.2	1630.8
Ny5	1264.6	55.3	1297.0	1200.7
H6	1324.1	126.0	1246.0	1469.5
E6	1264.6	55.3	1297.0	1200.7
Ny6	1297.2	2.1	1294.8	1298.5
H7	1200.5	11.2	1200.0	1201.1
E7	1233.5	0.7	1137.0	1330.1
Ny7	1200.0	155.6	1090.0	1310.1
H8	1411.1	164.6	1234.8	1561.0
E8	1211.0	60.3	1141.7	1251.0
Ny8	1262.5	147.9	1149.2	1429.9
K 1/4	1351.5	109.2	1225.7	1423.5
Ny 1/4	1351.5	109.2	1225.7	1423.5
Sz 1/4	1253.2	30.5	1232.9	1288.3
K 180	1351.5	109.2	1225.7	1423.5
Ny 180	1111.1	31.6	1092.9	1147.7
Sz180	1123.8	66.0	1047.5	1161.9
GK Emese	1153.0	75.3	1066.0	1197.4

GK Illona	1220.8	57.0	1155.0	1266.0
GK Erzsébet	1130.0	15.9	1120.4	1148.4
KWS Nemesis	1812.3	8.0	1805.0	1821.0
KWS Lupus	1949.3	4.0	1943.0	1951.0
Biserka	1949.2	6.1	1944.9	1953.5
Rumenka	1480.6	160.8	1366.8	1594.3
Gyöngyszem	1381.2	40.1	1317.3	1445.1
Millet flour*	1038.9	6.3	1030.9	1045.9
Husked millet*	1344.8	1.3	1343.4	1346.5
Sorghum flour*	1308.6	1.3	1298.2	1317.4
Husked sorghum*	1353.2	1.3	1351.6	1354.7

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 9. Descriptive statistical analysis of sodium (Na) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	35.8	0.4	35.5	36.1
E1	33.8	2.1	34.1	33.5
Ny1	35.8	0.5	36.1	35.5
H2	50.3	3.8	47.9	55.1
E2	39.7	1.2	38.4	40.7
Ny2	26.2	6.5	22.3	33.8
H3	57.1	1.6	55.2	58.4
E3	35.4	3.5	39.4	33.0
Ny3	22.0	0.1	22.0	22.3
H4	34.4	16.5	22.7	46.13
E4	33.2	15.5	22.2	44.1
Ny4	56.7	2.07	55.2	58.1
H5	50.3	12.7	42.8	65.0
E5	40.8	4.3	38.3	45.8
Ny5	32.4	10.7	19.9	38.8
H6	50.1	6.9	42.1	54.5
E6	32.4	10.7	19.9	38.8
Ny6	34.7	6.1	31.1	41.8
H7	32.0	0.1	31.9	32.1
E7	32.7	0.1	32.1	33.3
Ny7	37.3	0.1	36.1	38.5
H8	43.3	12.3	40.9	45.6
E8	39.6	12.3	29.9	53.6
Ny8	30.6	6.0	23.6	34.8
K 1/4	43.6	17	23.9	54.9
Ny 1/4	34.6	1.5	23.6	35.5
Sz 1/4	26.8	0.9	25.8	27.5
K 180	37.5	42.7	36.6	38.5
Ny 180	28.1	1.0	26.9	28.7
Sz180	33.4	0.0	33.0	33.4
GK Emese	31.0	2.8	28.5	35.1

GK Illona	31.6	4.8	27.5	36.3
GK Erzsébet	35.6	4.8	32.5	38.7
KWS Nemesis	62.0	8.9	55.7	68.3
KWS Lupus	112.0	3.0	109.0	115
Biserka	29.9	1.1	28.4	29.9
Rumenka	21.8	0.7	21.3	22.3
Gyöngyszem	48.5	10.2	46.2	50.8
Millet flour*	43.9	0.0	43.9	44.1
Husked millet*	46.5	0.3	46.1	46.8
Sorghum flour*	36.4	0.1	36.1	36.5
Husked sorghum*	29.8	0.2	29.7	29.8

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 10. Descriptive statistical analysis of copper (Cu) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	3.1	0.7	3.0	3.1
E1	3.8	0.9	3.1	4.5
Ny1	3.1	0.1	3.2	3.3
H2	3.0	0.2	2.8	3.3
E2	3.6	0.1	3.5	3.8
Ny2	2.9	0.7	2.5	3.9
H3	3.5	0.6	2.8	3.9
E3	4.2	0.5	3.6	4.5
Ny3	2.8	0.3	2.5	3.1
H4	3.8	1.2	2.9	4.8
E4	3.3	1.5	2.2	4.4
Ny4	3.7	0.9	3.0	4.4
H5	3.9	0.7	3.1	4.4
E5	3.8	0.2	3.1	4.1
Ny5	3.9	0.7	4.3	4.4
H6	3.9	0.1	3.1	4.3
E6	3.9	0.7	4.3	4.4
Ny6	2.9	0.2	2.8	3.1
H7	3.3	0.8	2.7	4.1
E7	3.3	0.5	2.1	4.5
Ny7	4.1	0.8	3.9	4.1
H8	3.5	1.0	2.8	4.7
E8	3.6	0.7	2.8	4.7
Ny8	3.5	1.0	2.8	7.7
K 1/4	4.0	0.3	3.8	4.4
Ny 1/4	3.4	0.0	3.3	3.5
Sz 1/4	3.8	0.8	3.3	4.8
K 180	3.7	0.2	3.2	4.2
Ny 180	2.9	0.2	3.0	3.2
Sz180	3.1	0.0	3.0	3.2
GK Emese	3.8	0.5	3.5	4.4
GK Illona	4.4	0.9	3.8	5.5
GK Erzsébet	3.2	0.3	3.3	2.9

KWS Nemesis	4.8	0.0	4.8	4.1
KWS Lupus	4.7	0.0	4.2	4.7
Biserka	5.9	0.3	5.6	6.1
Rumenka	7.3	1.4	6.3	8.4
Gyöngyszem	7.5	1.1	6.1	9.0
Millet flour*	4.9	0.1	4.9	5.0
Husked millet*	3.5	0.1	3.5	3.5
Sorghum flour*	3.2	0.1	3.2	3.3
Husked sorghum*	3.4	0.0	3.4	3.4

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 11. Descriptive statistical analysis of iron (Fe) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	49.4	0.8	48.7	49.9
E1	59.4	14.9	48.8	69.9
Ny1	49.1	0.8	48.8	49.9
H2	56.4	10.0	44.8	62.3
E2	50.1	6.9	46.1	58.1
Ny2	48.9	8.2	44	58.5
H3	58.6	3.0	56.8	62.1
E3	55.7	7.9	46.6	60.6
Ny3	49.1	4.3	44.1	51.8
H4	58.87	5.7	54.79	62.95
E4	54.4	5.1	50.8	57.9
Ny4	54.9	1.5	53.79	55.95
H5	55.1	8.7	45	60.8
E5	51.6	7.0	47.5	59.7
Ny5	59.0	0.8	58.2	59.8
H6	52.9	1.3	52	54.4
E6	52.9	1.3	52	54.4
Ny6	55.0	2.1	52.5	56.8
H7	49.4	14.9	38.8	59.9
E7	51.8	12.8	42.8	60.9
Ny7	56.8	7.1	51.8	61.9
H8	57.2	2.3	53.3	57.6
E8	55	2.3	54.6	59.2
Ny8	55	2.3	53.3	57.6
K 1/4	47.4	2.8	44.6	50.3
Ny 1/4	43.2	2.6	38.5	45.2
Sz 1/4	43.3	4.2	38.5	46.5
K 180	35.9	13.7	20.8	47.8
Ny 180	40.6	1.5	38.8	41.5
Sz180	42.3	0.1	42.2	41.5
GK Emese	49.1	2.3	47.6	51.8
GK Illona	56.9	9.7	37.5	68.2

GK Erzsébet	42.9	4.7	37.5	45.6
KWS Nemesis	50.1	0.3	49.9	50.5
KWS Lupus	48.0	0.2	47.8	48.2
Biserka	49.7	1.2	45.8	53.5
Rumenka	51.7	4.2	48.7	54.7
Gyöngyszem	67.4	2.2	62.3	72.5
Millet flour*	39.9	0.0	39.8	40
Husked millet*	53.9	0.1	53.8	54.1
Sorghum flour*	42.6	0.1	42.5	42.7
Husked sorghum*	41.3	0.1	41.1	41.9

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 12. Descriptive statistical analysis of zinc (Zn) mg/kg in commercial *S. bicolor* and *P. miliceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	23.4	1.3	20.3	26.5
E1	24.3	1.3	23.3	25.2
Ny1	21.3	1.3	20.3	22.2
H2	19.1	3.5	17.0	21.2
E2	21.2	1.6	20.1	23.1
Ny2	21.6	1.2	23.0	20.8
H3	19.8	2.4	17.0	21.4
E3	23.9	3.7	19.5	26.1
Ny3	21.9	8.7	20.9	22.5
H4	24.1	2.9	22.1	26.2
E4	21.2	1.5	20.1	22.2
Ny4	21.3	2.7	19.3	23.2
H5	20.3	2.8	19.8	20.7
E5	22.8	2.8	20.3	25.3
Ny5	21.1	1.0	20.2	22.0
H6	20.2	1.9	19.1	22.4
E6	20.8	1.0	20.2	22.0
Ny6	20.6	0.3	17.3	22.5
H7	23.0	1.4	22.0	24.0
E7	20.6	0.7	20.1	21.2
Ny7	23.5	4.2	20.5	26.5
H8	24.0	3.2	20.4	26.5
E8	24.7	2.0	23.3	27.1
Ny8	24.0	3.2	20.6	27.1
K 1/4	25.4	1.9	24.1	27.6
Ny 1/4	24.2	0.29	23.9	24.5
Sz 1/4	25.0	2.7	24.0	25.6
K 180	20.0	14.2	14.2	24.6
Ny 180	22.7	0.8	21.8	23.1
Sz180	20.9	0.0	20.8	21.0
GK Emese	22.9	1.5	22.1	24.7

GK Illona	28.1	4.1	25.7	32.9
GK Erzsébet	19.4	0.4	19.0	19.6
KWS Nemesis	25.7	0.2	25.6	25.9
KWS Lupus	20.9	0.1	23.5	23.7
Biserka	31.4	4.1	28.9	33.6
Rumenka	27.8	4.1	23.6	31.9
Gyöngyszem	29.3	0.1	29.2	29.3
Millet flour*	23.0	0.1	22.9	23.0
Husked millet*	22.6	0.1	22.4	22.6
Sorghum flour*	18.4	0.8	17.6	19.1
Husked sorghum*	21.0	0.0	22.9	21.1

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 13. Descriptive statistical analysis of manganese (Mn) mg/kg in commercial *S. bicolor* *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	16.1	0.1	16.1	16.2
E1	26.5	0.4	26.1	26.8
Ny1	35.8	0.4	36.1	35.5
H2	17.3	1.9	18.4	15.1
E2	22.9	5.6	19.6	29.5
Ny2	19.2	8.9	14.0	29.6
H3	18.0	0.3	17.8	18.3
E3	28.3	7.3	19.8	32.6
Ny3	13.9	0.1	13.8	14.2
H4	27.6	6.6	22.9	32.4
E4	17.8	2.7	15.8	19.7
Ny4	21.4	0.7	20.9	21.9
H5	22.0	3.6	17.8	24.2
E5	23.0	6.1	19.5	30.2
Ny5	18.2	1.4	17.3	19.9
H6	20.5	3.1	17.7	24.0
E6	18.2	1.4	17.3	19.9
Ny6	21.6	3.5	17.5	23.7
H7	19.2	5.5	15.3	23.1
E7	18.8	3.8	16.1	21.5
Ny7	21.8	2.4	20.1	23.5
H8	20.9	4.0	16.3	23.4
E8	26.7	3.3	23.4	30.1
Ny8	21.0	5.1	16.4	26.5
K 1/4	13.3	0.1	13.1	13.4
Ny 1/4	13.7	0.2	13.5	14.4
Sz 1/4	14.0	0.4	13.5	14.4
K 180	12.9	0.8	12.0	13.4
Ny 180	12.7	1.2	11.4	13.4
Sz180	14.4	0.3	14.2	14.8

GK Emese	16.1	3.3	14.1	19.6
GK Illona	18.1	4.5	13.9	23.0
GK Erzsébet	15.7	1.7	13.8	17.1
KWS Nemesis	21.1	0.1	21.0	21.2
KWS Lupus	15.2	0.3	15.2	15.3
Biserka	13.9	2.2	12.3	15.5
Rumenka	13.9	0.5	13.7	13.9
Gyöngyszem	19.2	4.8	19.0	19.5
Millet flour*	10.0	0.0	10.0	10.0
Husked millet*	7.1	0.0	7.0	7.1
Sorghum flour*	15.1	0.0	15.1	15.3
Husked sorghum*	8.0	0.0	8.0	8.1

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 14. Descriptive statistical analysis of crude protein (N) mg/kg in commercial *S. bicolor* and *P. miliaceum* whole flour grain attributed to various varieties and origin sources

Factors	Mean	Std. Deviation	Minimum	Maximum
H1	17.2	0.3	16.2	18.1
E1	13.0	0.6	12.5	13.4
Ny1	13.7	0.5	13.4	14.1
H2	15.2	6.8	15.2	15.3
E2	17.2	0.0	17.1	17.3
Ny2	14.3	0.0	13.6	14.9
H3	13.5	0.0	13.1	13.9
E3	18.3	0.0	18.2	18.5
Ny3	16.3	0.0	16.2	16.4
H4	12.4	1.0	11.5	13.4
E4	13.0	0.5	12.4	13.5
Ny4	14.0	0.1	13.8	14.0
H5	19.8	0.0	19.7	19.9
E5	16.5	0.0	16.3	16.6
Ny5	14.3	0.0	14.3	14.4
H6	13.4	0.0	13.3	13.5
E6	16.0	0.1	15.9	16.0
Ny6	14.0	0.1	13.8	13.9
H7	11.3	0.1	10.9	11.8
E7	16.6	0.0	16.5	16.6
Ny7	14.6	0.0	14.5	14.8
H8	15.6	0.0	15.6	15.6
E8	16.8	0.0	16.8	16.9
Ny8	18.0	0.0	17.9	18.2
K 1/4	17.9	0.0	17.9	18.0
Ny 1/4	17.2	0.0	17.1	17.2
Sz 1/4	17.7	0.0	17.7	17.7
K 180	17.1	0.2	16.9	17.4
Ny 180	18.4	0.0	18.3	18.5
Sz180	15.1	0.0	14.9	15.4
GK Emese	18.8	0.0	18.7	18.9

GK Illona	19.2	0.0	19.0	19.5
GK Erzsébet	12.4	1.7	10.1	14.4
KWS Nemesis	18	0.3	17.7	18.3
KWS Lupus	9.9	0.4	9.4	10.3
Biserka	17.9	5.0	17.0	17.9
Rumenka	16.8	0.2	16.6	16.9
Gyöngyszem	19.5	0.2	19.3	19.3
Millet flour*	19.9	0.0	19.9	19.9
Husked millet*	21.6	0.1	21.5	21.7
Sorghum flour*	16.9	0.1	16.8	17.0
Husked sorghum*	14.3	0.0	14.3	14.4

- The presented values were calculated based on the dry matter; the star sign (*) refers to the products that were sourced from the retail store

Appendix 15. Descriptive analysis of the macro-mineral contents of diverse *S.bicolor* race varieties on male sterility line

Codes	Processed grains	Pericarp colour	D.M g/kg	Protein g/kg	P mg/kg	S mg/kg	Ca mg/kg	K mg/kg	Mg mg/kg	Na mg/kg
1	1		986±0.03	22±0.13	4201±36.1	1727±12.4	174±6.1	3932±2926.3	2643±0.16	23±0.3
	2	Brown	987±0.47	8±0.64	2630±201.7	1372±54.3	114±14.3	2965±166.9	1721±447.5	18±2.1
	3		987±0.47	14±0.21	9993±347.8	1889±130.2	505±37.7	9404±771.8	4722±166.3	34±2.4
2	1		890±0.13	23±0.03	3877±81.2	1517±202.1	176±8.0	3650±41.0	2313±0.13	21±.37
	2	White	990±0.05	16±0.26	3005±496.7	1591±32.6	93±43.7	2929±87.4	1645±541.6	18±3.6
	3		990±0.05	13±0.10	9525±492.9	1705±95.3	607±36.3	9830±1260.4	4951±458.3	36±3.6
3	1		991±0.04	12±0.60	3712±14.2	1760±67.2	261.3±12.1	2983±0.4	2344±0.27	21±1.0
	2	Brown	991±0.04	9±0.58	2396±119.2	1579±142.6	122±31.2	3729±469.0	1645±468.8	20±2.9
	3		991±0.04	18±0.55	9525±492.9	1705±95.3	607±36.3	9830±1260.4	4951±458.3	36±3.9
4	1		990±0.05	20±0.11	4185±128.0	1555±20.3	243±11.2	4047±11.0	2350±0.33	27±0.5
	2	Brown	990±0.05	15±0.02	8452±1527.8	1412±67.5	90±7.3	9565±208.01	2906±507.6	17±0.6
	3		990±0.05	12±0.09	8953±579.6	1703±214.2	484±100.8	9345±319.1	4312±233.3	44±1.2
5	1		98.4±0.28	17±0.41	2155±125.1	1437±234.0	192±118.5	2289±192.2	1399±248.8	23±0.3
	2	Brown	991±0.06	8±0.02	1712±539.8	1293±49.4	87±35.7	2213±170.5	1525±97.7	17±3.1
	3		991±0.05	12±0.09	2128±407.8	1716±85.5	453±75.3	3160±663.0	2342±277.2	32±1.6
6	1		980±0.04	20±0.02	3505±97.1	1612±164.0	264±21.8	5326±29.0	2384±21.0	22±9.7
	2	White	991±0.07	6±0.02	2081±756.2	1482±99.3	107±30.3	2450±9.3	143±521.4	21±2.8
	3		991±0.06	12±0.10	9199±383.6	1688±16.9	419±29.1	8442±198.0	4142±94.2	33±1.0
7	1	Brown	894±0.02	13±0.01	2521±357.1	1522±246.2	323±153.1	2514±180.8	1298±336.2	27±005
	2		991±0.05	12±0.02	1861±481.1	1251±23.2	114±13.6	1397±129.4	1351±342.2	20±4.3
	3		991±0.05	19±0.03	8130±2209.8	1815±237.4	494±29.1	8606±947.0	4542±617.7	34±2.7
8	1		984±0.07	20±0.02	3733±112.3	1312±75.0	296±.15	4041±0.24	2516±0.0	29±12.5
	2	White	991±0.06	9±0.32	2958±638.7	1141±62.8	155±10.9	2945±542.9	1735±338.5	18±1.9
	3		991±0.06	11±0.11	9199±383.6	1688±16.9	419±29.1	8442±198.0	4142±94.2	33±1.0
9	1		985±0.08	12±0.001	2742±93.4	1347±254.0	274±.38	2547±447.0	1714±222.4	27±0.1
	2	White	991±0.06	19±0.33	2215±644.5	1192±48.1	173±46.3	2782±55.9	1316±429.0	24±2.0
	3		990±0.02	10±0.01	7564±2281.3	1689±213.7	427±31.1	4105±1054.7	4065±590.8	40±6.8
10	1	White	983±0.23	18±0.03	2644±179.1	1586±415.4	319±298.5	4617±311.0	1578±254.7	28±57.1
	2		990±0.02	14±0.35	2165±644.5	1402±166.2	169±23.6	1659±138.1	782±2.2	22±6.1
	3		990±0.02	15.±0.39	10013±464.3	1652±47.4	494±111.6	10455±646.6	4744±363.6	41±5.2
11	1		983±0.23	8±0.01	2390±372.1	1562±280.2	335±173.0	5261±197.0	1712±155.6	30±14.7
	2	Brown	990±0.02	15.5±0.38	1981±771.7	1331±103.0	142±2.4	2820±544.0	1176±496.2	25±2.9
	3		990±0.02	10±0.26	10019±622.0	1931±95.9	488±24.2	10868±94.9	4045±191.8	42±2.7
12	1		986±0.01	19±0.50	2790±1824.1	1044±237.0	534±119.5	5524±456.8	1942±942.3	34±10.8
	2	Brown	991±0.06	12±0.34	1315±255.3	901±35.5	461±24.8	2753±266.4	929±163.5	58±2.5
	3		991±0.06	18±0.08	10259±690.5	1688±82.1	536±126.9	9067±205.5	4620±168.1	39±3.9
13	1	Brown	985±0.04	12±0.01	3589±114.6	1244±.24	509±2.12	2936±3.8	2226±16.3	66±12.8
	2		990±0.05	9±0.53	2307±611.3	1086±47.6	415±91.8	1328±136.6	1424±401.3	62±4.7

	3		990±0.02	14±0.59	4860±240.1	1335±44.8	425±42.4	6163±368.7	2994±99.6	82±2.6
14	1		985±0.13	8±0.01	3740±520.9	1150±77.2	274±4.6	4252±0.27	1536±0.17	73±1.1
	2	White	991±0.02	.93±0.16	2546±662.8	1057±66.3	411±11.7	3787±514.5	1068±290.3	43±2.9
	3		990±0.02	14±0.12	9607±1194.0	1622±117.4	684±29.3	11949±30.2	4398±520.0	91±3.2
15	1		981±0.11	15±0.02	3667±86.1	1095±18.6	419±20.0	3443±126.8	1883±.01	60±8.3
	2	Brown	990±0.01	8±0.42	2279±804.6	885±56.9	379±31.5	3056±451.6	1139±395.0	57±3.3
	3		990±0.02	19±0.12	7319±841.9	1344±149.5	574±32.0	6363±636.1	3079±261.6	74±6.9
16	1		985±0.36	7.8±0.003	3529±1038.1	975±94.3	611±94.5	3308±637.2	1747±547.3	63±1.0
	2	Brown	990±0.06	13±0.15	1664±937.6	1154±3.8	500±17.2	2365±221.9	788±461.6	61±2.3
	3		991±0.02	15±0.09	7378±752.8	1325±118.2	506±21.7	7421±89.3	3404±81.7	73±3.6
17	1		983±0.15	13±0.1	4285±383.3	1154±293.6	544±174.2	3308±637.2	1747±547.3	59±9.8
	2	Brown	991±0.01	15±0.39	1777±459.9	1118±136.8	423±11.7	2354±123.3	980±249.5	53±3.0
	3		990±0.07	15±0.25	6023±558.9	1131±81.5	499±24.9	6628±1017.2	2713±483.6	75±3.7
18	1		986±0.01	12±0.11	3723±249.1	1236±64.5	478±3.1	3526±500.0	1828±42.6	61±6.9
	2	White	990±0.01	12±0.10	2323±433.9	935±53.6	411±37.6	1995±349.4	1149±196.8	50±.71
	3		990±0.05	14±0.41	6652±161.1	1430±34.8	718±21.2	7449±185.4	3249±215.9	77±18.6
19	1		990±0.60	10±0.1	3001±752.4	1308±177.1	265±29.4	3521±1008.2	1684±334.9	66±5.0
	2	Brown	990±0.07	15±0.30	2629±907.6	757±84.5	433±64.4	2234±744.3	1198±362.6	69±4.9
	3		99.12±0.01	17±0.40	8826±492.5	1331±85.8	767±40.5	7765±542.1	3434±146.2	71±1.8
20	1		984±0.01	12±0.1	3546±92.1	1022±49.6	534±22.2	3760±1416.0	2182±1103.3	79±7.1
	2	Brown	990±0.05	15±0.47	2706±650.5	757±84.5	433±64.4	3061±795.8	1198±362.6	69±4.9
	3		990±0.02	12±0.53	5909±133.4	1308±32.4	783±52.6	8330±786.5	3406±293.9	81±3.3
21	1		984±0.06	10±0.01	3792±123.2	1179±19.0	426±4.0	4014±11.3	1523±0.01	74±0.12
	2	White	990±0.05	15±0.39	2471±530.7	1119±136.8	398±14.5	2412±373.3	1044±211.1	68±4.6
	3		990±0.02	12±0.53	83322±878.9	1206±160.0	721±130.8	10177±1035.2	3856±504.6	93±8.2
Ground grains	-	-	0.23	<.001	<.001	<.001	<.001	<.001	0.28	0.02
Husked grains	-	-	<.001	<.001	0.49	<.001	<.001	0.91	0.21	0.05

Appendix 16. Descriptive analysis of the micromineral contents of *S.bicolor* race on male sterility line

Codes	Processed grains	Pericarp	Fe	Zn	Cu	Mn
		colour	mg/kg	mg/kg	mg/kg	mg/kg
1	1		83±0.7	29±0.3	4±0.2	16±1.1
	2	Brown	25±0.7	24±6.8	5±.7	11±2.8
	3		145±42.6	55±14.7	8±2.8	37±13.6
2	1		39±0.3	31±0.1	6.4±.3	15±2.2
	2	White	39±10.5	15±5.1	3±0.70	8±3.0
	3		23±10.6	101±21.9	13±4.4	57±20.7
3	1		35±0.1	28±0.1	4±0.2	15±2.2
	2	Brown	26±0.6	18±6.7	3±0.7	9±3.1
	3		23±10.6	101±21.9	13±4.4	57±20.7
4	1		30±0.8	30±0.1	3±0.5	14±2.3
	2	Brown	94±1.1	22±11.3	10±0.2	33±2.4
	3		13±2.5	72±2.4	9±1.5	36±1.5
5	1		39±15.2	24±7.0	3±0.2	16±1.1
	2	Brown	30±3.0	12±4.2	3±0.5	8±0.9
	3		26±0.0	61±0.9	5±1.7	19±1.0
6	1		46±0.1	26±0.2	4±0.1	25±6.5
	2	White	24±0.8	16±2.5	3±0.5	9±3.2
	3		28±0.6	81±4.2	10±1.1	32±1.4
7	1	Brown	26±2.2	25±4.6	5±1.1	16±0.1
	2		18±0.8	13±3.5	2±0.2	11±3.4
	3		15±2.4	67±9.0	10±0.5	40±6.3
8	1		28±0.3	25±0.2	6±0.41	21±7.4
	2	White	26±0.6	15±2.8	3±0.5	15±3.5
	3		28±0.6	81±4.2	10±1.1	32±1.4
9	1		31±12.9	19±7.9	2±0.3	24±1.1
	2	White	26±0.4	16±4.0	3±0.3	10±2.6
	3		20±4.0	66±17.2	13±2.3	55±11.4
10	1	White	35±12.0	23±7.8	4±1.0	19±7.9
	2		17±1.1	13±4.6	1±0.4	9±3.6
	3		28±5.5	81±5.5	14±2.2	53±6.6
11	1		36±8.4	23±3.6	4±0.5	13±2.9
	2	Brown	48±11.0	11±3.8	2±0.5	8±1.9
	3		27±3.3	78±19.1	11±0.2	61±4.6
12	1		37±6.9	22±7.0	5±2.5	20±4.4
	2	Brown	33±2.4	13±2.6	4±0.2	8±1.9
	3		147±7.5	65±4.5	8±0.4	37±4.4

13	1	Brown	44±.41	24±0.2	6±0.3	15±0.7
	2		44±14.1	14±5.2	3±0.1	9±2.4
	3		79±17.0	52±3.3	10±1.9	29±5.5
14	1		41±0.2	17±0.4	4±0.4	14±0.1
	2	White	31±5.5	13±3.4	2±0.1	9±2.9
	3		122±5.9	66±3.8	14±0.9	40±.2
15	1		50±0.5	22±.10	3±0.4	15±1.8
	2	Brown	31±8.3	12±4.0	2±0.2	9±3.0
	3		68±17.7	42±1.2	8±1.7	24±3.4
16	1		34±5.3	18±4.1	3±0.9	18±1.2
	2	Brown	21±7.5	9±4.9	3±0.7	5±1.3
	3		77±26.1	40±7.3	4±0.9	26±5.7
17	1		49±2.7	25±2.8	4±0.6	16±2.0
	2	Brown	34±5.7	10±2.4	2±0.5	12±2.0
	3		60±16.0	60±9.4	10±1.8	18±1.4
18	1		51±.65	22±2.3	4±0.2	15±2.4
	2	White	35±6.2	14±2.3	3±0.2	10±1.8
	3		115±10.8	45±3.6	6±0.2	36±11.8
19	1		40±11.0	17±5.0	3±0.6	15±3.4
	2	Brown	28±6.0	10±2.4	2±0.4	7±1.3
	3		132±12.2	53±2.0	8±0.4	35±4.9
20	1		34±0.2	16±6.1	3±2.2	17±10.1
	2	Brown	28±6.0	10±2.4	2±0.4	7±1.3
	3		71±11.5	56±4.5	10±2.3	30±5.6
21	1		48±.12	15±0.1	4±0.1	16±0.1
	2	White	35±3.6	10±0.6	3±0.1	5±1.7
	3		121±10.6	45±2.8	6±0.4	40±2.1
Ground grains	-	-	<.001	0.001	<.001	<.001
Husked grains	-	-	<.001	0.14	<.001	0.01

Appendix 17. Descriptive analysis of the macro-mineral contents of Kafir race on male sterility line

Codes	Processed grains	Pericarp Colour	D.M g/kg	Protein g/kg	P mg/kg	S mg/kg	Ca mg/kg	K mg/kg	Mg mg/kg	Na mg/kg
22	1	Brown	981±0.06	13±.001	2263±306.2	1241±370.0	661±248.6	4642±375.2	1159±890.0	74±7.9
	2		991±0.05	9±0.07	1654±280.7	757±84.5	409±4.5	2239±386.0	885±154.2	68±4.6
	3		990±0.02	13±0.53	10486±737.6	1462±144.0	741±208.1	9869±673.8	3585±245.2	78±4.3
23	1	White	986±0.03	11±0.10	2762±184.2	815±192.2	475±132.3	3012±797.5	1450±416.4	64±8.9
	2		991±0.49	14±0.22	1343±467.4	715±53.9	412±34.4	1891±381.2	711±248.8	64±2.8
	3		993±0.32	10±0.39	7802±266.5	1728±166.5	775±124.3	9784±1094.4	3718±549.5	84±8.7
24	1	White	987±0.98	19±0.12	3741±1127.1	1000±32.2	523±133.3	4660±2206.3	1395±176.4	70±5.6
	2		990±3.45	9.3±0.12	2232±280.1	989±34.5	431±36.1	2113±215.9	1318±146.4	67±3.5
	3		991±0.44	8±0.02	8046±737.1	1226±135.3	770±93.8	9362±744.1	3491±125.0	77±4.2
25	1	White	984±0.24	14±0.02	3105±66.0	1046±16.0	554±5.0	3234±170.8	1611±0.1	64±0.1
	2		991±0.01	14±0.01	1317±570.9	804±54.1	389±6.1	1406±449.9	703±315.5	54±1.9
	3		991±0.07	16±1.30	5561±1002.1	1091±111.8	708±51.6	6977±401.5	2842±389.7	85±9.2
26	1	White	985±0.08	13±0.04	2453±313.1	996±202.0	4438±123.3	3253±1483.5	2718±949.4	66±8.4
	2		990±0.12	11±0.05	999±218.6	877±75.2	370±90.1	1390±201.2	517±122.6	61±5.7
	3		993±0.02	20±0.77	7467±249.9	1182±190.3	698±40.3	7749±584.7	3253±250.8	80±9.4
27	1	White	985±0.08	132±0.10	2069±11.0	1160±13.0	609±9.0	3253±1483.5	1264±0.1	79±1.0
	2		990±0.03	118±0.18	1670±338.6	1048±56.9	476±98.7	2690±429.4	1007±198.5	67±6.1
	3		991±0.05	10.0±0.50	6635±441.6	1289±103.2	648±15.7	8964±1260.2	3383±360.7	82±3.2
28	1	White	983±0.01	13±0.10	2546±392.2	1106±349.1	599±233.7	2589±291.0	1434±389.2	70±9.5
	2		990±0.30	12±0.31	2230±358.5	896±21.0	450±71.1	2459±292.4	1070±210.0	64±2.0
	3		991±0.08	21±0.78	5079±440.9	1724±70.4	619±54.7	7773±306.8	2736±106.0	86±7.9
29	1	White	981±0.01	11±0.10	2766±219.3	1262±327	592±220.1	3043±681	1218±217.3	65±7.1
	2		990±0.04	14±0.14	2356±425.2	1066±42.6	432±55.9	2668±330.5	1306±142.3	61±2.0
	3		990±0.02	17±1.1	8184±2356.8	1594±121.3	7100±26.2	10249±799.8	3411±354.9	79±7.7
30	1	White	981±1.01	7.0±0.05	4299±317.9	892±212.1	566±94.2	2704±175.9	1464±311.8	77±8.9
	2		990±0.20	14±0.15	1946±528.2	765±48.5	483±55.5	2188±352.5	1045±250.1	64±8.1
	3		991±0.05	15±0.003	8682±1384.8	1745±148.0	935±103.4	9980±435.5	3995±49.0	93±9.5
31	1	White	980±0.46	10±0.001	2060±540.1	1140±316.2	518±217.0	6371±452.4	1674±335.0	78±10.9
	2		991±0.03	13±0.30	1980±574.6	954±78.5	385±80.9	2430±467.7	1038±268.0	64±8.1
	3		991±0.07	19±0.36	9473±711.0	1281±184.2	993±80.1	9589±1128.2	3412±204.3	91±5.6
32	1	White	987±0.16	16±0.03	2780±864.3	1016±153.0	485±68.0	3709±1972.9	1483±395.9	67±9.1
	2		991±0.03	12±0.08	2402±655.9	933±89.0	450±71.1	2596±614.7	1165±309.9	61±1.9
	3		991±0.01	13±0.23	8755±1848.8	1597±137.5	802±156.3	11658±696.1	4074±233.3	81±5.2
33	1	White	980±0.21	12±1.0	2995±83.8	1188±292.0	463±143.3	5270±349.1	1477±333.5	67±8.0
	2		990±0.11	12±0.19	2566±491.3	1013±507.0	382±24.5	2269±399.1	1311±215.5	64±6.6
	3		980±0.10	16±0.35	7998±682.2	1263±127.6	928±122.3	9301±604.5	3132±90.6	81±9.4
34	1	White	982±0.19	10±0.01	3020±943.2	998±159.0	450±76.4	2894±840.2	1905±646.2	70±9.0
	2		990±0.05	19±0.03	1974±291.2	900±45.8	365±87.0	2677±287.9	1084±154.7	65±2.2
	3		990±0.03	18±0.15	9399±810.6	1499±4.1	558±76.5	9283±226.2	3837±126.3	85±6.8
35	1	White	987±0.02	16±0.30	3337±523.2	1051±237.1	278±159.4	2894±840.2	1544±326.3	38±5.0
	2		989±0.01	12±0.34	2368±526.1	907±50.4	186±11.2	2447±448.5	1144±257.1	35±1.4
	3		989±0.50	17±0.09	4729±790.3	1279±135.4	768±165.6	8445±792.6	2656±187.7	44±1.3
36	1	White	980±0.01	14±0.12	2692±598.4	1123±236.6	288±178	3295±1472.3	2135±869.4	41±2.4
	2		990±0.06	8.5±0.70	2501±568.3	987±63.1	179±21.4	2457±450.9	1153±218.3	39±1.3
	3		99.0±0.23	16±0.01	7839±812.7	1385±97.1	631±113.1	8976±429.2	3377±124.9	45±2.9

37	1	White	983±0.01	11±0.001	2375±1462.0	1062±180.0	291±220	4846±381.7	1800±902.3	38±7.8
	2		99.1±0.03	13±0.07	1554±471.1	958±80.6	214±33.0	2122±470.0	730±264.5	34±4.0
	3		990±0.54	12±0.25	8624±809.5	1437±93.3	523±75.7	9042±296.9	3198±190.0	49±3.8
38	1	White	987±0.01	73±0.02	3254±361.1	960±165.2	518±122.0	2681±271.3	1705±237.8	62±7.2
	2		990±0.06	12±0.88	1130±148.5	856±21.4	431±40.0	202±411.0	721±253.3	57±2.2
	3		990±0.76	18±0.25	8105±277.5	1391±176.4	585±110.0	8076±1118.7	3107±387.9	72±3.6
39	1	White	982±0.21	13±0.005	4348±274.0	1113±169.0	403±9.9	4448±3570.5	1362±173.9	62±8.3
	2		991±0.03	10±0.15	2753±367.9	1007±23.3	312±78.8	2369±233.3	1329±184.8	57±3.2
	3		993±0.42	17±0.11	8304±1036.8	1242±120.6	605.2±76.0	9951±1241.5	3772±189.2	76±6.7
40	1	White	985±0.03	11±0.10	3097±607.2	1039±159.9	339±181.0	3797±1549.2	1478±331.8	54±14.6
	2		991±0.44	16±0.50	1623±0.1	897±.01	169±6.5	1935±27.0	836±10.0	39±.10
	3		991±0.22	17±0.08	8420±1164.2	1352±74.4	626±17.3	8523±118.2	3534±205.8	71±4.0
41	1	White	985±0.03	18±0.01	2826±573.1	1095±175.4	372±34.6	3494±1644.0	1419±199.1	44±27.3
	2		990±0.05	10±0.12	1780±501.6	1046±84.1	180±125.6	1822±434.0	922±282.4	24±1.5
	3		991±0.28	13±0.23	7162±106.8	1233±40.7	678±195.6	8171±47.7	3432±73.5	36±3.6
42	1	White	986±0.02	15±0.04	3324±1692.0	1269±256.2	605±254.2	5285±2440.3	1188±125.8	53±18.0
	2		99.1±0.02	16±0.32	2492±861.3	1037±73.4	365±132.1	2522±704.7	968±308.2	51±9.1
	3		990±0.82	20±0.68	7162±870.8	1224±146.2	641±127.0	8003±195.9	3379±191.8	76±10.3
43	1	White	985±0.01	10±0.01	3657±1946.0	1188±256.3	555±291.0	5879±2889.8	1948±808.9	58±14.7
	2		991±0.01	10±0.44	1878±501.2	1037±73.4	480±83.2	2501±496.8	1035±275.4	53±6.3
	3		990±0.06	15±0.23	10979±1088.0	1643±115.1	567±101.0	11084±622.9	4099±138.9	79±8.9
44	1	White	985±0.01	10±0.08	3699±1957.2	1209±222.1	500±170.5	2632±497.4	1987±779.3	59±17.0
	2		990±0.01	8.8±0.48	2194±550.9	1161±59.9	338±48.3	2491±529.5	1062±273.4	46±5.0
	3		990±0.01	24±0.85	6012±241.1	1506±122.4	958±83.7	9196±645.7	2936±144.9	87±9.9
45	1	White	984±0.01	10±0.06	2384±280.0	1086±23.6	449±121.8	2968±815.4	1458±313.6	58±14.1
	2		991±0.03	9.2±0.36	1320±432.4	933±99.2	405±21.6	1767±487.3	729±289.0	63±90.0
	3		991±0.26	18±0.64	6829±1079.8	1449±56.2	853±32.0	9047±403.7	2904±116.6	74±.83
46	1	White	985±0.10	18±0.03	2532±271	1121±260.9	513±97.2	4341±1161.4	2117±918.6	75±9.7
	2		990±0.04	7±0.35	1380±359.8	849±33.7	410±43.7	1620±317.6	772±214.0	68±4.6
	3		990±0.88	14±0.09	6737±272.6	1567±31.6	747±83.2	9543±628.0	3102±128.5	88±4.5
47	1	White	986±0.63	17±0.04	1801±641.1	1056±325.2	508±126.7	3155±297.8	1852±853.4	67±10.9
	2		981±0.11	13±0.12	1787±433.6	849±62.1	480±14.3	2731±595.1	940±235.8	53±4.0
	3		991±0.02	15±0.30	6695±170.0	1401±23.9	683±65.7	8038±561.7	3147±109.1	87±10.3
48	1	White	985±0.30	18±0.52	3090±593.8	934±115.0	492±17.2	3001±686.4	1553±154.5	58±7.0
	2		991±0.05	12±0.28	1360±471.4	858±22.4	478±83.3	1434±508.1	523±303.4	53±5.9
	3		990±0.78	15±0.05	6198±183.4	1417±14.1	657±65.7	9407±821.4	2923±730.0	87±12.1
49	1	White	987±0.04	10±0.36	2898±420.0	1043±327.0	549±134.3	2978±343.2	2047±115.2	62±10.0
	2		991±0.01	13±0.01	1364±507.3	820±43.3	475±126.4	1628±318.8	719±300.4	56±8.4
	3		991±0.10	13±0.10	9904±197.1	1311±19.3	670±46.9	9266±915.8	3395±194.4	77±3.5
50	1	White	988±0.34	16±0.05	2887±.15.0	954±66.1	635±.13	3867±1131.4	1326±.16	64±.50
	2		990±0.02	12±0.28	1103±412.2	734±26.7	400±78.9	1482±287.8	531±230.4	55±3.6
	3		991±0.24	15±0.16	7989±770.3	1506±15.5	652±28.2	7582±187.9	3733±220.5	58±5.7
51	1	White	982±0.01	20±0.04	3307±1252.0	1029±258.0	520±111.0	3058±638.0	1907±654.4	68±14.5
	2		991±0.02	9±0.14	1580±265.9	875±48.7	448±48.7	2726±379.1	929±5.5	61±9.0
	3		90±90.30	14±0.63	12380±227.3	1519±86.4	773±121.9	8760±631.8	653±45.2	63±12.3
Ground grains	-	-	<.001	<.001	0.58	0.32	0.55	0.81	0.02	<.001
Husked grains	-	-	<.001	<.001	0.76	<.001	<.001	0.08	0.93	<.001

Appendix 18. Descriptive analysis of the micromineral contents of Kafir race on male sterility line

Codes	Processed grains	Pericarp Colour	Fe mg/kg	Zn mg/kg	Cu mg/kg	Mn mg/kg
22	1	Brown	26±3.5	21±9.7	7±0.1	19±6.0
	2		23±0.3	10±1.0	2±0.4	10±0.9
	3		136±3.4	42±1.5	8±0.1	43±3.0
23	1	White	28±5.3	24±7.9	4±1.0	23±6.2
	2		41±.46	9±3.3	3±0.5	6±1.1
	3		44±7.2	78±10.2	16±1.6	21±3.9
24	1	White	30±9.9	22±4.1	5±0.1	17±9.9
	2		27±7.0	8±3.5	3±0.2	13±2.6
	3		79±6.6	64±5.5	11±1.0	37±3.6
25	1	White	51±1.1	23±.1	3±0.9	12±0.7
	2		24±1.0	6±2.0	3±0.5	8±.93
	3		75±10.6	51±7.0	10±0.7	26±3.9
26	1	White	54±4.0	27±2.1	4±0.1	22±8.2
	2		35±6.0	6±2.0	3±0.8	13±.22
	3		97±4.2	67±4.6	11±1.2	35±1.4
27	1	White	29±0.1	16±0.1	4±1.3	17±0.1
	2		59±0.3	12±2.5	4±0.5	9±3.4
	3		92±16.8	72±16.8	10±1.5	35±4.0
28	1	White	40±10.2	35±24.2	2±0.3	28±0.8
	2		41±7.7	11±2.7	3±0.4	7±0.97
	3		93±17.2	45±4.9	10±3.0	42±3.8
29	1	White	40±7.6	37±29.7	4±0.8	24±4.7
	2		40±3.9	16±0.6	3±0.5	7±1.7
	3		121±17.2	68±8.2	12±1.3	30±2.4
30	1	White	56±27.5	16±12.0	3±0.7	23±7.4
	2		40±36.5	10±2.3	3±0.5	8±2.2
	3		92±6.8	71±5.6	14±2.0	30±1.9
31	1	White	59±27.4	22±6.9	4±0.8	17±8.1
	2		43±5.7	11±3.4	3±0.6	8±2.2
	3		93±5.0	53±5.6	10±0.8	28±4.1
32	1	White	45±6.1	28±1.2	4±1.5	23±7.0
	2		50±6.6	11±3.3	3±0.5	7±1.4
	3		107±12.6	58±5.8	12±1.7	38±4.6
33	1	White	46±4.7	26±2.9	4±1.5	17±1.8
	2		33±9.5	11±2.2	3±0.2	9±1.4
	3		87±7.3	46±4.3	7±1.1	26±1.9

34	1	White	41±14.9	26±3.4	4±1.6	15±2.1
	2		50±6.6	12±1.9	2±0.4	8±2.0
	3		72±8.9	59±9.4	13±1.0	27±2.7
35	1	White	38±13.6	22±7.6	5±2.1	14±4.0
	2		39±14.4	11±3.1	2±0.0	8±2.0
	3		90±7.1	37±3.9	8±0.9	26±2.9
36	1	White	36±11.6	22±7.6	3±0.5	17±1.5
	2		32±9.9	12±2.6	2±0.2	7±1.6
	3		77±3.9	53±1.6	12±1.4	28±0.9
37	1	White	31±12.3	22.6.6	5±4.2	19±6.0
	2		32±12.7	11±3.8	2±1.0	7±2.1
	3		89±3.9	54±1.6	10±0.6	27±5.0
38	1	White	28±1.8	21±7.4	5±1.3	18±8.7
	2		36±19.2	10±2.8	3±0.5	6±4.0
	3		94±7.3	56±3.9	10±0.8	34±1.0
39	1	White	36±8.6	20±4.3	4±0.4	13±4.5
	2		32±4.5	13±1.7	3±0.6	9±1.0
	3		88±4.7	56±5.1	12±0.5	32±1.7
40	1	White	45±29.0	27±4.6	3±1.3	23±4.7
	2		29±1.1	8±0.03	2±0.1	8±1.1
	3		101±26.0	54±2.3	13±1.2	31±1.8
41	1	White	36±8.8	16±4.1	3±1.0	14±3.3
	2		29±6.8	10±2.6	3±0.4	8±2.5
	3		100±0.1	49±.95	8±0.1	35±1.6
42	1	White	45±7.4	40±31.4	4±2.2	13±1.8
	2		29±6.8	14±48.2	2±0.7	8±2.7
	3		112±4.2	48±4.0	6±0.3	35±2.9
43	1	White	34±10.5	24±8.1	6±2.6	23±8.5
	2		29±6.5	12±3.7	3±0.6	7±1.9
	3		76±4.7	78±3.8	13±2.1	44±0.3
44	1	White	39±15.1	25±6.6	4±1.8	16±4.6
	2		32±7.2	15±2.4	3±0.6	9±1.5
	3		77±5.6	41±2.5	9±0.5	25±2.3
45	1	White	34±7.8	17±3.6	3±0.7	19±1.0
	2		25±7.3	11±2.8	2±0.5	6±2.0
	3		100±11.4	49±.67	9±0.4	28±1.0
46	1	White	40±14.5	20±1.7	4±2.2	17±2.6
	2		23±4.2	9±2.5	3±0.3	5±1.4
	3		79±4.8	50±2.6	7±0.6	26±0.9
47	1	White	39±5.3	21±8.0	4±1.7	16±3.4
	2		28±5.7	10±2.3	3±0.1	11±2.6
	3		77±4.2	44±2.8	9±0.4	26±2.3
48	1	White	49±1.4	21±5.8	4±1.0	14±4.0

	2		20±7.4	6±2.3	2±.5	4±2.0
	3		80±9.7	36±2.1	7±1.3	38±0.80
49	1	White	40±7.1	20±6.0	3±0.7	19±6.2
	2		24±7.5	9±3.7	2±0.5	4±1.5
	3		98±7.2	59±7.3	10±2.0	29±1.5
50	1	White	34±.05	15±.10	4±0.6	10±0.21
	2		17±4.7	5±2.0	2±0.5	5±0.30
	3		99±5.9	6±.27	11±3.1	59±2.5
51	1	White	40±11.1	24±7.0	3±0.8	15.3.8
	2		33±4.5	12±3.9	3±0.1	8±00.84
	3		58±7.1	29±22.5	8±0.5	34±8.2
Ground grains	-	-	0.05	0.53	0.04	0.28
Husked grains	-	-	<.001	0.88	0.54	0.04

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