Thesis of doctoral (PhD) dissertation

EFFECT OF NITROGEN SUPPLY ON THE QUALITY PARAMETERS AND FOOD INDUSTRIAL UTILIZATION OF COMMON MILLET AND GRAIN SORGHUM

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1. BACKGROUND AND OBJECTIVES OF THE DOCTORAL DISSERTATION

'*Can modern society exist without field crops*?', Mihály Sárvári questioned in his book of 'Cultivation of other alternative cereals' (2011). The subsistence of some ethnic groups depends solely on the existence of food based on arable crops. With respect to animal husbandry, the presence of arable crops is also indispensable (Sárvári, 2011).

Today, the growing frequency of extreme weather conditions more and more draw our attention to those plants that have excellent adaptability. The study of potentials of non-traditional, highly adaptive and undemanding plants is crucial (Dias-Martins et al., 2018).

In Hungary, increasingly extreme weather conditions, such as the increase in average temperature and the reduction in the amount of precipitation, can be perceived and will be more common in the future. However, it is not advisable to abandon domestic cereal production opportunities, changes should be considered during cultivation and new goals and proportions should be set (Láng et al., 2007). As a result, extremely drought-tolerant plants such as millet, which have a very low water demand (Mándi and Gocs, 2004) or sorghum, whose cultivation remains profitable provide potential despite unfavourable conditions (Ábrahám and Virágné Pintér, 2016).

Nitrogen is important to mention, which is an essential part of life and of the cell that holds and transmits information (Füleky and Sárdi, 2014). Nitrogen deficiency also results in a reduction in plant growth and protein formation. However, overdose of nitrogen shows increased development, time of ripening may be delayed, and grain slope may occur (Loch and Nosticzius, 2004). However, several people refrain from fertilizers, despite the fact that fertilizers are produced of raw materials in the nature by chemical synthesis, so the name refers to their production (Loch and Nosticzius, 2004).

Research history confirms that the consumption of non-standard cereals is a tradition. For a long time, they have been a stable part of crop production, however, they have lost their cultivation and field trials. As a certified nutritionist, I aimed to study the nutritional parameters of alternative cereals and the effects of different levels of nutrient supply on the cultivars and hybrids of the University of Debrecen, as well as on the plants at the research institute. Thus, the effects of treatments may be evaluated on samples of plants grown under controlled experimental conditions. Therefore, the basis of my doctoral dissertation is the cultivated millet and grain sorghum as alternative grains.

The data on the effect of fertilization on grain sorghum and common millet are mostly presented on the average yield, the element content and uptake, but there is little literature available in the context of quality, therefore my aims were:

1. To find out the optimum quantities for the most important quality parameters – that determine the nutrient composition of the plants tested – with increasing amount of nitrogen.
2. In the course of my doctoral dissertation I aimed at the quality testing of flour produced from the sorghum and millet seed available for consumers. In addition to the analysis of basic quality parameters, such as protein content and change in starch content, I also put great emphasis on the determination of starch composition.
3. My further task was to determine the content of dietary fiber, determine the content of total phenolic antioxidant compounds, and study other physiologically important quality parameters, such as fat content or fatty acid composition, and their evaluation based on the requirements for food use.
4. My goal is to determine the macro- and microelement concentrations and their ratios and compare the results to the optimum for both grain and human nutrition, which results provide additional information for both the producer and the consumer.

In my dissertation, not only the statistical analysis of the effect of N took place, since I had the opportunity to compare the reactions of millet varieties. The statistical analysis therefore aimed at assessing the impact of the variety and the fertilizer effect and their combination. Based on the results obtained from the determination of the quality parameters of the plants examined, it was possible to carry out the correlation analysis between nutrients and element contents.

2. MATERIAL AND METHOD

2.1. Characterisation of the experimental area, soil and climatic conditions

The small-plot experiment was set up in the parcels of Research Institute of Karcag, Institutes for Agricultural Research and Educational Farm, University of Debrecen, in 2016 and 2017.

The experiments were set up on the parcels of 17th experiment of the National Fertilization Content Experiments (OMTK) of 1966/67. OMTK fertilizer doses were modified in 2012 and crop rotation was reduced to cultivated plants in Karcag.

The experiments were set on B1, H2 and G3 parcels, in long-term field experiment and in cultivated garden. In 2016, the experiment was set on H2 parcel, where the preceding crop was winter barley and winter wheat. In 2017, millet varieties were set in long-term field experiment (0 kg/ha, 40 kg/ha, 80 kg/ha, 120 kg/ha N) on G3 parcel and B1 parcel in cultivated garden (160 kg/ha, 200 kg/ha N). Winter rape and boer millet were the preceding crops on B1 and G3 parcels, respectively.

The ground of the area is flat and levelled. Based on the grouping of arable land, it can be categorized as slightly firm chernozem soil while according to the soil genetic classification it is meadow phaeozems. Plasticity, according to Arany (K_A) is 42-48, the physical soil type of the area is clay loam. Its pH is 0 - 25 cm acidic, pH_{KCl} 4.5-5.4. The N-supply of the topsoil in the 0-25 cm layer can be considered medium and good. P-supply is approppriate and very weak, K-supply is classified as weak, medium, appropriate and rich (MÉM NAK, 1987).

2.2. Experimental plant varieties

- Millet variety "Maxi"
- Millet variety "Lovászpatonai pirosmagvú"
- Grain sorghum hybrid "Zádor"

2.3. The introduction of fertilization experiment

The selected fertilizer was applied in the form of sodium nitrate/MAS and monoammonium phosphate (MAP). In 2016, the size of millet (Maxi and Lovászpatonai pirosmagvú) experimental parcels were 4.5 x 4.8 m = 21.6 m^2, in 2017 they were 4.5 x 5.3 m = 23.8 m^2. The amount of seed is 40 kg/ha, the seed distance is 1.7 cm (Maxi) and 1.1 cm (Lovászpatonai pirosmagvú), the row distance is 12 cm and the seed depth is 3-4 cm. The size of the plot in the case of grain sorghum (Zádor) was 4.5 x 7.8 m = 35.1 m^2 in 2016, while it was 7.7 x 7.0 m = 53.9 m^2 in 2017. The amount of seed applied was 7 kg/ha, the seed distance was 5 cm, the row distance was 76.2 cm, and the seed depth was 4-6 cm.

The selected treatments were 0 kg/ha (control), 40 kg/ha, 80 kg/ha, 120 kg/ha, 160 kg/ha and 200 kg/ha N for each variety. The experiment was limited to the study of N-effect. The fertilization experiment took place in a repetition of 4 times.

The parcels were set in a randomized arrangement (Figure 1). The field experiment is illustrated in Figures 2, 3 and 4.

Repetition I.	Repetition II.	Repetition III.	Repetition IV.
5	4	Ø	1
Spraying path			
4	2	1	3
3	Ø	2	5
Spraying path			
2	5	3	Ø
1	3	4	2
Spraying path			
Ø	1	5	4

Figure 1. Experimental parcels

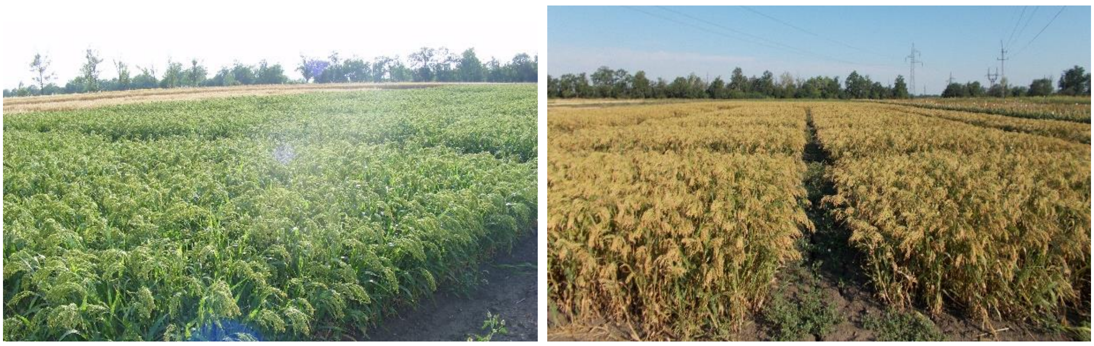

Figure 2. Experiment of Maxi millet on 10th June 2017 and 2nd August (Photo: Murányi és Jevcsák, 2017)

Figure 3 Experiment of Lovászpatonai pirosmagvú millet on 10^{th} July 2017 and 2^{nd} August

(Photo: Murányi and Jevcsák, 2017)

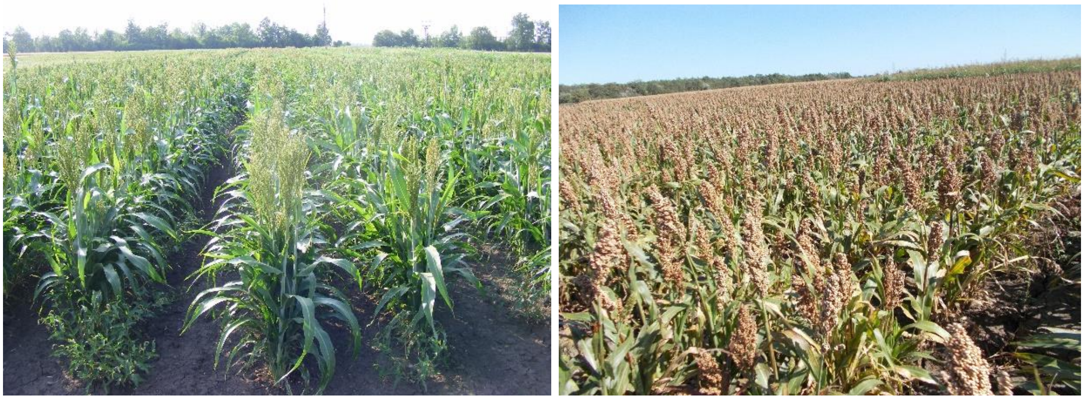

Figure 4. Experiment of grain sorghum hybrid Zádor on 10^{th} July 2017 and 14^{th} September

(Photo: Murányi és Jevcsák, 2017)

The moisture and dry matter content of the samples were determined by drying chamber. In 2016, the grain moisture at harvesting was 19.0-21.0% and 16.5-18.0% for Maxi and Lovászpatonai pirosmagvú millet, with a yield of 3.77-4.30 t/ha and 3.35-3.51 t/ha. The grain moisture of Zádor grain sorghum is 13%, in case of the whole yield was not harvested, at the time of ripening a certain number of panicle were collected and threshed, providing 0.5-1 kg of sorghum seed for each analytical test. In 2017, Maxi millet grain moisture content at harvest was 10.9-16.0%, with a yield of 2.80-3.70 t/ha. The grain moisture content of the Lovászpatonai pirosmagvú millet is 11.0-17.5%, with a yield of 1.40-2.56 t/ha. The grain moisture of the Zádor sorghum was 10.7% to 11.0%, with a yield of 6.44-6.92 t/ha.

2.4. Applied quality analytical methods

During my research I applied field, physical and laboratory examinations of seed samples of grain sorghum and common millet varieties using different amounts of nitrogen. After harvesting, the samples were delivered to the Food Industry Innovation Centre, Institute of Food Technology, Faculty of Agriculture, Food Science and Environmental Management, University of Debrecen, where they were milled. Flour with a particle size of less than 250 µm was used for analysis and stored at 4 °C until the start of the analytical measurements. The laboratory tests were carried out in the laboratories of the Institute of Food Technology, Faculty of Agriculture, Food Science and Environmental Management, University of Debrecen and the Institute of Food Science, which were as follows:

- Determination of mass of thousand seeds (MSZ EN ISO 520:2011)
- Determination of moisture content (MSZ 6367-3:1983)
- Determination of ash content (MSZ EN 1135:1995)
- Determination of nitrogen and protein content (MSZ EN 12135:1999)
- Determination of starch content (MSZ 6830-18:1988)
- Determination of starch composition (Megazyme enzymatic methods):
- Determination of amylose/amylopectin ratio (Gibson et al., 1997)
- Determination of starch damage (Megazyme Starch Damage, 2015)
- Determination of resistant starch content (Megazyme Resistant Starch, 2015)
- Determination of fat content (MSZ 6369-15:1982)
- Determination of fatty acid composition (Morrison and Smith, 1964; MSZ 19928:1986; MSZ ISO 5508:1992; MSZ EN ISO 661:2006)
- Determination of the content of total phenolic antioxidant compounds (Kim et al, 2003)
- Determination of fiber content (MÉ 3-2-2008/1)
- Determination of element composition (Kovács et al., 1996)

The following standards were used to evaluate results:

- Millet (MSZ 6340:1985)
- Sorghum for human consumption (MSZ 6273:2017)

2.5. Methods used for statistical evaluation of results

With the results of the field repetition of the samples I received a set of data for which basic statistical methods could be used.

Data were processed by Microsoft Excel 2013. I conducted charts and tables with means and standard deviations. During the statistical analysis I performed one-way variance analysis (fertilizer dose) and two-way variance analysis (fertilizer dose and variety). At the applied fertilizer doses 0 kg/ha N, 40 kg/ha N, 80 kg/ha N, 120 kg/ha N, 160 kg/ha N and 200 kg/ha N effect, applied to fertilizer doses and combination of fertilizers and the effects of 2 millet variations (Maxi and Lovászpatonai pirosmagvú) were evaluated. By calculating the significant difference ($SzD_{5\%}$) I could evaluate the effect of such factors on which the value of the deviations was already above the margin of error. The following method was used to indicate the significance levels: * p<0,05; ** p<0,01; *** p<0,001 (Sváb, 1981; Berzsenyi, 2015).

As a measure of effect size, i.e. to estimate the size of the treatment, I use the Parcial Eta Squared values (Levine and Hullett, 2002; Richardson, 2011; Huzsvai, 2004; Huzsvai and Vincze, 2012). The value shows the percentage of the independent variable influencing the variance of the dependent variable. The value of the indicator can range from 0 to 1.00; zero means independence and 1.00 represents deterministic relationship. The closer it is to 1, the stronger the correlation between the two variables is. According to Cohen (1988), values between 0.01 and 0.06 are small, between 0.06 and 0.13 are medium, while values of 0.14 and above are high (Michielsen et al., 2007).

The correlations between the examined nutrients and nutrient elements were evaluated by correlation analysis (Huzsvai, 2004; Huzsvai and Vincze, 2012). Consequently, it can be examined whether two measurement variables change in a similar way - *positive correlation* - or in the opposite direction - *negative correlation*. The value of the coefficient may vary from +1 to -1, and if there is no connection between the values of the two variables, the correlation value will be zero or near zero. The data were processed by SPSS version 23.

3. RESULTS

The weather in the two experimental years was significantly different, affecting both qualitative and quantitative parameters of the varieties. In contrast to the average precipitation of the last 50 years, in the experimental year of 2017, both the sorghum hybrids and the 2 millet varieties had lower precipitation (measurement results of the Research Institute of Karcag, Institutes for Agricultural Research and Educational Farm, University of Debrecen) during their propagation periods. This change is well reflected in the yields, as the yields of the tested plants in the 2016 experimental year showed a higher result compared to 2017.

On the basis of the results of mass of thousand seeds, we also receive feedback on the weather factors. For both millet varieties, I found that the values in the first experimental year were higher than the values for the next study year. In both millet varieties there was a variety effect in both years. In the case of sorghum hybrid, I also noticed that the first year showed a higher value of a mass of thousand seeds compared to the second year. In the first study year, there was a significant difference between fertilizer treatments. Compared to the control sample, an increase was observed in the value of the mass of thousand seeds up to the treatment of 160 kg/ha N.

In the ash content of 2016, there was a significant difference between millet flour samples, both the N fertilizer effect and the combination of variety and fertilizer effect. Ayub et al. (1999) used 0-0 kg/ha, 50-0 kg/ha, 100-0 kg/ha, 50-50 kg/ha, 100-50 kg/ha and 100-100 kg/ha NP treatments which resulted in an increase in the ash content of the samples. The highest treatment resulted in the highest ash content and the lowest value in the control sample. In contrast, no such change was found in ash content testing. The highest treatment yielded the highest ash content in a single sample (2016 Lovászpatonai millet sample) while in one sample the control was the highest (Maxi millet sample 2016). In the samples of the following year, up to 80 kg/ha of nitrogen was mostly observed, and the ash content of the samples showed a decrease. Zádor sorghum samples did not show any increasing tendency for treatment, either.

During my study, I found that increasing nitrogen fertilization had a positive effect on the protein content of millet varieties. In one case (2017), I observed that there was no significant change between 160 kg/ha and 200 kg/ha of nitrogen treatment, the treatments with the highest dose did not significantly increase the protein content of the samples. In the experimental year of 2017, I measured the average protein content of both varieties.

There was a significant difference amongst the effect of the variety, the effects of fertilizer treatments, and the combination of variety and fertilizer effect in the first year. During the examination of Zádor sorghum, I found that the control sample had the lowest protein content and the increased nitrogen treatment boosted the protein value of sorghum samples. In terms of the results of the second experimental year, there was no difference between the treatment of 80 kg/ha and 120 kg/ha of nitrogen, the higher dose did not increase this value. In the first year of study, there was a significant difference in dose effect.

I did not find any significant difference in the starch content of the samples. In the experimental year of 2017, there was a variety effect, but no clear trend can be observed between the amount of starch content.

By examining the starch composition, it can be concluded that the values obtained are characteristic of the variety. The amylose content of the two millet varieties was in most cases between 25% and 32%, ranging from 20% to 32% in the literature (Annor et al. 2017). On average, I measured values between 22 and 25% in sorghum, compared to 24-33% in millet flour (Yousif et al., 2012) which is lower than in literature. Further literature was found on waxy sorghum suggesting that the increasing amount of nitrogen initially increased and then reduced the amylopectin ratio (Wang et al., 2017). In my experiment, I did not experience similar change, but in my case, I observed that the second year showed a lower amylose content compared to the results of the first experimental year.

Ratio of damaged starch is an important parameter for flour quality due to its good water absorption capacity (Allister et al., 2008). Examining the results of the starch damage in the millet and sorghum samples, I found that in the first experimental year I had a higher value than in the second year.

Resistant starch content is receiving increasing attention due to its physiological function. This parameter is a characteristic of the variety depending on the grain size of the starch and also depends on the milling process. For both millet varieties, higher resistant starch contents were measured compared to the literature (Ragaee et al., 2006; Arendt and Zannini, 2013). For grain sorghum, I measured the same contents of resistant starch as can be found in the literature (Khan et al., 2013). This value was higher in the second year than in the first experimental year. Overall, these values can be considered stable with changing nutrient supply.

Analysing the fat content of the millet samples of 2016, I found that there was a significant difference between the varieties as well as between fertilizer treatments. In addition, there was a statistically proved difference between the variety and fertilizer effect in 2017. In the experimental year of 2016, there was a significant difference in the fertilizer effect at the Zádor grain sorghum hybrid. Examining the fatty acid composition of the samples, I found that in 2016 the ratio of both saturated and unsaturated fatty acids was within a narrow range of limits. The ratio of fatty acids to each other did not change significantly as a result of the treatments, so they are characteristic of the variety. The most dominant fatty acids in all three plants were linoleic acid, oleic acid and palmitic acid. The amount of essential fatty acids was 47% to 67% on average for the samples I tested.

Examining the content of total phenolic antioxidant compounds of millet varieties, the effect of the varieties was proved in both years. The higher phenolic compound of the Maxi millet has a content against the millet variety of Lovászpatonai. However, 2017 showed lower values, which may be due to more drought weather, but the temperature may have affected this parameter. This is not the case with sorghum samples, because the second experimental year did not resulted lower phenolic compound content. Sorghum hybrid had significantly higher content of phenolic antioxidant compounds than millet varieties.

Ayub et al. (1999) studied the effect of NP treatments on fiber content that was also 0-0 kg/ha, 50-0 kg/ha, 100-0 kg/ha, 50-50 kg/ha, 100-50 kg/ha and 100-100 kg/ha. It was found that the treatments had a statistically proven positive effect on the fiber content of the samples. In my research, in most cases I could observe an increase in dietary fiber content up to 160 kg/ha of nitrogen treatment. In millet varieties, there was a fertilizer effect that could not be proved in the sorghum samples.

According to the literature data, the N, S and Cu contents of the millet increase due to nitrogen fertilization (Kádár, 2005). Examining the macro elements, the concentration of N showed an increasing tendency as a result of increasing treatments, as expected. In most cases, the content of P showed a decrease as it was expected due to the N:P antagonism. In 2016, the Maxi millet P content resulted in a continuous decrease in treatment, with the exception of the 120 kg/ha nitrogen dose, where the lowest value was measured. In the same year, there was a continuous decrease in the 120 kg/ha N treatment with the Lovászpatonai millet sample. There was a significant difference between varieties and fertilizer doses. In the samples of 2017, Maxi showed a reduction, with the exception of 120 and 200 kg/ha N treatment, where a slight increase was observed. I received a higher value than the Lovászpatonai millet control sample during the 40 kg/ha nitrogen treatment and then again, a continuous decrease in P content.

N and K elements are characterized by synergism, however, in the majority of millet samples I have determined a slight decrease in K concentration. It is known that millet has low Ca content. This was also confirmed by the results of the samples I examined. There was a significant difference between the varieties, fertilizer doses, and the variety and fertilizer dose combinations.

The N and Mg elements are characterized by synergism; however, a decrease in Mg concentration was found as an effect of the treatments. There was a significant difference between the varieties and between the fertilizer doses.

For most S treatments, the increase in concentration was determined by the effect of increasing N doses, which supports the synergistic relationship between the N-S elements. In the experimental year of 2016, the treatment of both types resulted in the highest value of 160 kg/ha nitrogen. There was a significant difference between the varieties as well as between the fertilizer doses. In 2017, the Maxi millet control sample had the lowest S content, and treatments always increased the S-concentration of the samples, the 200 kg/ha N resulted in the highest value. Three treatments (40, 120, and 160 kg/ha N) in the Lovászpatonai millet resulted higher S contents compared to the control sample. There was a significant difference between varieties and between fertilizer doses and the combination of variety and fertilizer.

The concentration of Na showed mostly decreasing trend. In Na content study, I could observe significant differences between the varieties, treatments, variety and treatment combination only in 2016.

Based on Kádár's (2005) experiment, nitrogen treatment increases Cu content. In my experiment, I measured the increasing Cu content of the Maxi millet under the influence of nitrogen treatment.

In the study of Fe content, the effect of varieties was prevalent in 2016, according to which the concentration of Fe was higher in the Lovászpatonai millet samples. In contrast, in 2017, there was a significant difference between fertilizer doses, between the variety and the fertilizer combination. Regarding Maxi millet, three treatments increased the Fe content (40, 80 and 120 kg/ha N), while in the case of Lovászpatonai millet, only 120 kg/ha of nitrogen rose. In 2016, the Zn nutrient also had a variety effect. I measured higher results again with the Lovászpatonai millet sample. In 2017, there was a significant difference in each case. Treatment increased Zn content in most samples. In 2016, Mn content was lower than treatment for both species due to treatment. In contrast, in 2017, the samples of the year had higher Mn content in many cases as a result of the treatments. There was a significant difference between fertilizer doses in both years.

Analysing the content of the macro element of the Zádor sorghum, I found that the N concentration showed an increasing tendency as a result of the treatments. The P concentration of the samples showed decreasing concentration by N:P antagonism. In 2016, I measured higher P content in samples than in 2017, but in both years the treatments reduced the concentration of P. In the first experimental year, there was a significant difference between fertilizer treatments.

The N and K elements are characterized by synergism, but in Zádor sorghum, as in millet samples, a slight decrease in K concentration was found. N and Mg elements can be characterized by synergism, but there was no continuous increase in N samples under the examined samples. Significant differences were found in the 2016 experimental year. The N and S elements are synergistic, but there was no significant difference between the fertilizer treatments of Zádor sorghum.

The N and Cu elements are characterized by synergism, which was shown in the experimental year 2016 of the examined samples. The N and Fe elements are antagonists, which can be established on the basis of the results of the examined samples, as a slight decrease in Fe content was observed due to increasing N treatment. There was a statistically proved significant difference in treatment effects only in 2017. The N and Mn elements were antagonists of each other, the evaluated samples showed a slight decrease in Mn content by the increasing N treatments, but the effect of treatments were not statistically proved.

A correlation analysis confirm the synergistic and antagonistic connections of nutrients and mineral elements. For example, the starch-K, N-K, N-S showed positive correlations, while N-P, P-Fe, P-Cu, Mg-Na showed negative ones.

In many cases, the ratios of elements typical to the optimal nutritional status of the plants were found. The ratio of N:K (grain sorghum), P: Zn, P: Fe and P:Cu (common millet and grain sorghum) is also considered appropriate.

A number of experimental samples are characterized by an optimal ratio for human nutrition. The ratio of Fe:Cu and P:Mg to grain sorghum, while the ratio of Fe:Mn to millet proved favourable. I found a large shift in the K:Na elements due to the Na is present in the samples in very low amounts. However, this value is beneficial, as in most cases, we take more Na into our body in daily life, than the recommended daily intake.

4. NEW SCIENTIFIC RESULTS OF THE DISSERTATION

1. It can be concluded that the value of examined common millet varieties and grain sorghum hybrid is largely determined by their protein content and can be increased by the nutrient supply. The 40-160 kg/ha nitrogen treatments resulted an increase in protein concentration in the examined crops, but the dose of 200 kg/ha N did not result significant growth in protein content. In addition, under the cultivation conditions we examined, the requirement for crude protein content of sorghum in the 6273:2017 Hungarian Standard may only be satisfied if higher than 80 kg/ha N is used.
2. The starch composition did not change significantly as a result of the parameters studied, so under different cultivation conditions 22-31% amylose content, 1.43-3.00% of damaged starch and 2.2-3.1 g/100 g of resistant starch may be close to the expected.
3. I found that the treatments did not significantly change the ratio of fatty acids, so they are characteristic of the variety. The linoleic acid (45% - 67%), oleic acid (18% - 33%) and palmitic acid (10% - 18%) were the fatty acids in the highest proportions in the examined sorghum and millet varieties.
4. It can be stated that the dietary fiber content of the millet flour samples examined in most cases showed an increase until the application of the dose of 160 kg/ha nitrogen. No trend can be observed for flour samples of grain sorghum.
5. N fertilizer treatments have no statistically proved effect on the content of total phenolic antioxidant compounds in the flour samples tested. Lovászpatonai millet contained the lowest value, 16-18 mg GAE/100 g, followed by Maxi millet, 18-23 mg GAE/100 g, while the highest concentration of Zádor sorghum flour samples contained antioxidant compounds, 97-98 mg GAE/100 g.
6. I found that the change of concentrations of the elements under the influence of nitrogen treatment depends on the particular element. It can be stated that the elemental content of the common millet varieties changes more intensively as a result of the nitrogen treatment than the element content of the examined grain sorghum.
7. It can be stated that element ratios optimal for plant nutrition status were observed in the ratio of N:K (grain sorghum), P:Zn, P:Fe and P:Cu (millet and grain sorghum). It

can be stated that the ratio of Fe:Cu and P:Mg in the case of grain sorghum, and the Fe:Mn ratio in the case of millet showed the optimal ratios for human nutrition.

5. PRACTICAL RESULTS

1. Based on my results, I suggest that due to the increasingly frequent extreme weather conditions, more emphasis should be placed on alternative cereals, both in research and in cultivation, as the plants I have studied have a number of favourable quality parameters, and it require more in-depth evaluation. There is little information available to investigate the evolution of these parameters as a result of agrotechnical factors.
2. With respect to crop production, it is important to apply nitrogen economically and optimally as it influences the amount of important nutrients. The operational implementation of nitrogen fertilization also requires consideration of economic and environmental aspects, as my results show that a dose of 200 kg/ha N did not result growth in protein content in a large extend on the phaeozems soil studied. In order to comply with the quality requirements for sorghum for human consumption, an application of a dose of at least 80 kg/ha N is required under the growing conditions of my study.
3. The amount of dietary fiber content is very important in terms of physiological function, and most of the samples also showed an increase to 160 kg/ha of nitrogen. Considering this parameter, it can also be stated that the application of a dose of 200 kg/ha nitrogen will no longer result in a particular change in the value of the dietary fiber content of the examined plants, so it is advisable not to apply this large dose if the aim is to increase the dietary fiber content, also, for non-wholegrain flour.
4. The properties of the starch are given a cardinal role in the processing of cereal processing technology. I found that nitrogen fertilization has no effect on these properties, nor does it affect the amount of amylose, nor the starch damage and the resistant starch content. Similarly, the fatty acid composition does not change as a result of agrotechnical factors.

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List of publications related to the dissertation

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1. **Jevcsák, S.**, Sipos, P.: Termesztett köles és szemes cirok felhasználása, a termékek fizikai, kémiai és reológiai tulajdonságainak vizsgálata.
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