Thesis of doctoral (PhD) dissertation

EXAMINATION OF THE EFFECT OF FERTILIZATION AND FORECROP IN A LONG-TERM EXPERIMENT ON THE BAKING PROPERTIES OF WHEAT GENOTYPES WITH INNOVATIVE STATISTICAL METHODS

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1. Introduction and objectives

In Hungary, winter wheat has the highest economic value among the cereals (*Horváth, 2014*), where there is a tradition of growing high-quality wheat (*Bedő et al., 2018*) because of the domestic climatic conditions (*Gasztonyi, 2004*).

The research of winter wheat quality dates back for many decades, where several findings and cause-and-effects have been made however, continuous studying within long-term experiments is indispensable for the following reasons. The average lifetime of varieties is constantly decreasing (*Pepó and Sárvári, 2011*). There is an urgent need to take steps towards sustainability to avoid soil exploitation, over-fertilization, also our agrotechnical knowledge has to be improved so the growing population can be supplied furthermore by agriculture. The effects of climate change, biotic and abiotic stress factors are becoming more acute. However, in recent decades, high-quality flour has become a definite expectation as a consequence of automatization and the appearance of frozen technology in the baking industry. It is important to note that Hungarian wheat production can easily cover domestic wheat demand, so farmers sell each year significant quantities of wheat for export. Nonetheless, the exporting countries set strict quality criteria where pricing and takeover are based on quality indicators. Because of the reasons mentioned above, there is a renewed demand for high-quality wheat flour.

In Hungary, the quality of wheat flour shows a fluctuating tendency, until then the yield in the last 6 years was above 5 t/ha in all cases (*KSH, 2020*). Over the past decade, the price difference between high and feed quality wheat has almost completely disappeared (*KSH, 2018*). As a result, cultivation has moved towards high yields and yield stability due to economic disinterest, while quality is becoming increasingly overshadowed, despite the fact that 65% of the produced wheat is used for food purposes (*Pepó, 2019*). For the reasons remarked above, demand for hybrid wheat is increasing (5-7%), which fulfils exceedingly the needs of farmers. Notwithstanding, the number of scientific works on the quality of hybrid wheat is very low so far.

Inhomogeneous flour quality due to the variety of Hungarian wheat assortment, and the importance of high-quality flour and its partial lack, which is compensated by the increasing use of vital gluten and baking agents motivated the choice of the thesis' topic.

I think that the quality of winter wheat is a very circumscribed topic, which is well illustrated by the fact that ScienceDirect has over 131,000 hits for the keyword "wheat quality". However, very few scientific works have been done in the past, which would have examined so comprehensively almost all the measurable quality parameters of wheat

flour and the correlations that can be established between them, also the effect of different agrotechnical treatments, agroecological attributes and wheat breeding with the most innovative programmed agristatistical solutions, all within the framework of a long-term experiment.

My objectives were as follows:

- to study the effect of different fertilizer treatments, forecrops and growing seasons on yield quality indicators of various (classical, modern and hybrid) winter wheat genotypes;
- to study the effect of different fertilizer treatments, forecrops and growing seasons on the yield of various winter wheat genotypes;
- to compare the natural nutrient and fertilizer use efficiency of different genotypes;
- to determine the correlations and the multicollinearities between yield quality parameters of winter wheat with agristatistical methods;
- to generate estimating equations for loaf volume and water absorption by multiple linear regression analysis;
- to compare quality indicators of the studied samples with the criteria of the Hungarian wheat standard and making a recommendation to the farmers;
- to create innovative and informative visualizations with programmed statistical methods to make large data sets easier to understand.

2. Materials and methods

2.1. The exposition of the experiment and the used methods

The field experiment was done at Látókép Experimental Farm (University of Debrecen) in two consecutive growing seasons (2018-2019) in split-split plot design. The research is part of a long-term experiment led by Prof. Dr. Péter Pepó. It was set up in 1983, near Debrecen in Hungary. The area belongs to calcareous chernozem and loamy type (Arany-type degree of fixity: 43-45) and has medium humus content (2.7-2.8%), medium P_2O_5 and K_2O supply and near-neutral pH (6.46).

The polyfactorial experiment consisted of a genotype and a forecrop testing part, also a certain segment formed a complement. In the first experimental part (4 factorial) I studied 2 winter wheat varieties (GK Öthalom and Mv Ispán), 2 forecrops (sweet corn and sunflower) and 3 nutrient treatments (control, $N_{90}PK$, $N_{150}PK$). In the second section (3 factorial) we studied 5 winter wheat genotypes (GK Öthalom, Mv Ispán, GK Csillag, KG Kunhalom and Hybiza), 3 nutrient treatments (control, $N_{90}PK$, $N_{150}PK$) in two growing seasons. In the last case, the forecrop was sweet corn.

The 50% of N and the whole amount of the P and K were applied in autumn, the remaining 50% of the N fertilizer was applied in spring as a top dressing on the 10 m^2 parcels. The examination of the different fertilizer levels was performed in 4 repetitions.

Firstly, the wheat batches were treated by a combinator. Next, the cleaned samples were measured by Mininfra Smart NIT grain analyser and SKCS 4100 at the Cereal Research Non-profit Ltd. (Figure 1.).

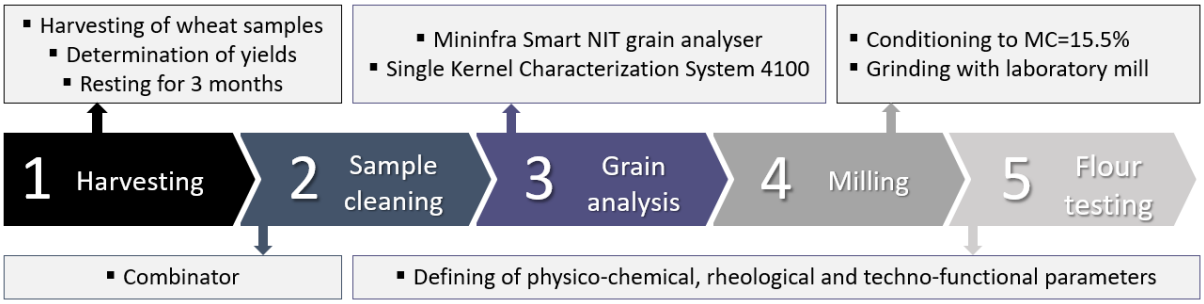


Figure 1. - The processing steps of experimental samples

Thereafter the moisture content of the samples was defined and then conditioned, the next day ground into flour using a Brabender Quadrumat Senior at the Institute of Food Engineering, University of Szeged. The amount of the fractions was measured during milling and the flour yield was determined. During the experiment, I measured 36

parameters like combined yield, physical grain properties, flour extraction, physicochemical and techno-functional parameters (Figure 2.).

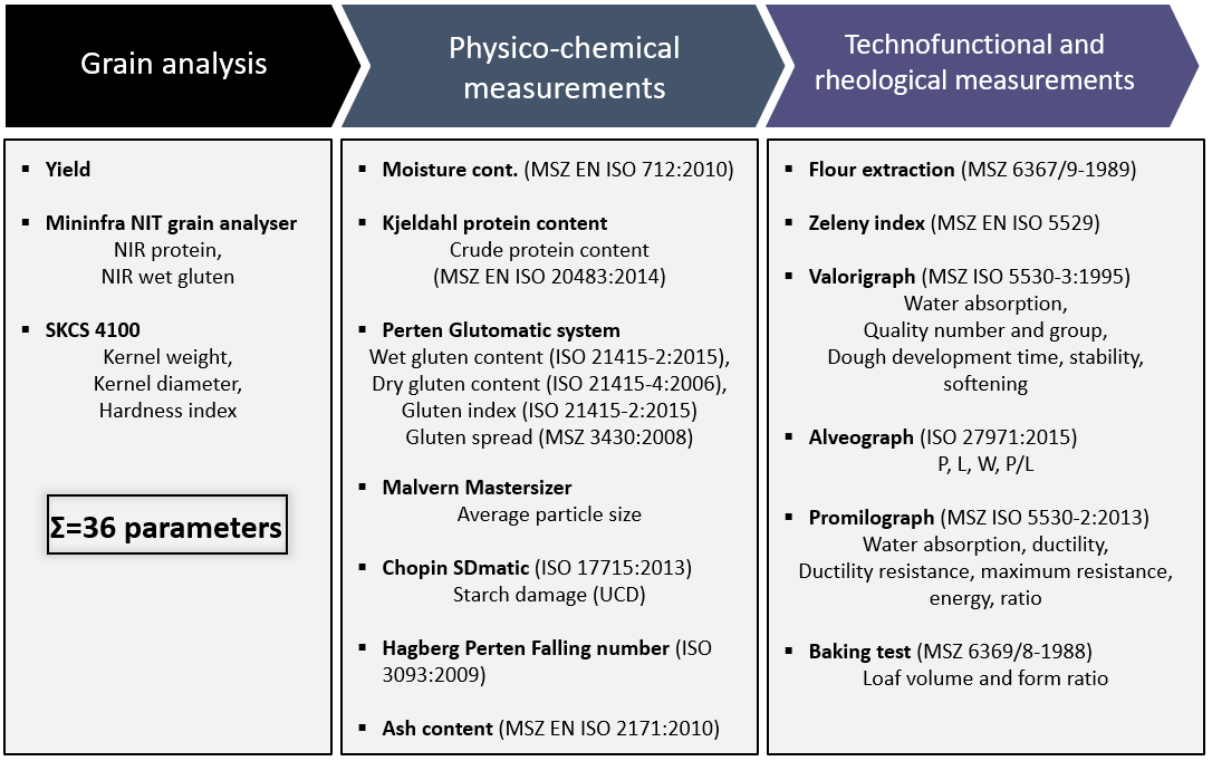


Figure 2. – The studied parameters of samples

2.2. The used statistical methods in the experiment

For data management, RStudio v3.6.1, Python v3.7 and IBM SPSS Statistics v25 were used. For arranging and filtering the data, dplyer package of R Studio was utilized. One-way ANOVA with LSD post-hoc tests on $P>0.05$ significance level of R Studio's agricolae package were performed. For graphical representation Matplotlib library (for radar, correlation matrix, waffle chart, heatmap) and Seaborn library (for joint plot and boxplot) were used.

Besides, I performed the principal component analysis of the SPSS program to get a comprehensive view of the correlations of the studied parameters and to determine principal components. I also performed multiple linear regression analysis, where the goal was to create an estimating equation by several explanatory variables. In addition, I determined the nitrogen use efficiency for protein (NUE_P) and yield (NUE_Y).

3. Results and discussion

3.1. Statistical analysis of the forecrop testing experiment

In the forecrop testing experiment (*n*=96) my goal was to study the effect of different agrotechnical factors (fertilizer, forecrop) on the quality parameters (33) of a modern and a classical winter wheat for 2 growing seasons. The outstanding yields of the first growing season (+21.7%) could be explained by the favourable water supply (+149.5 mm compared to the 30-year avg.), and the harsh weather conditions of the second season, like lack of precipitation and rapid warming in February (+2.5°C compared to the 30-year avg.) and March (+3°C compared to the 30-year avg.) (Figure 3.). However, the mild weather in April and May and the average annual precipitation of the second crop year had an optimal effect on the quality parameters.

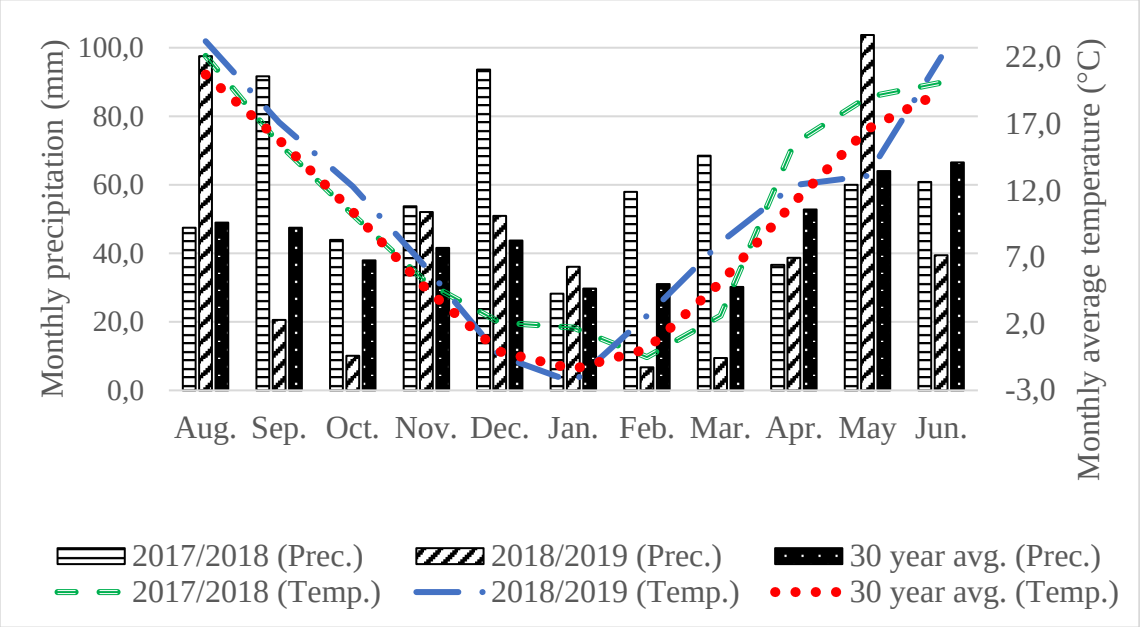


Figure 3. – The comparison of the monthly precipitations and average temperatures with the 30-year average values

The ecological factors of the 2018/2019 growing season significantly improved the quality of the classical wheat variety (GK Öthalom), which was observable mainly on the protein-linked attributes (crude protein, wet gluten, Zeleny index, gluten spread, valorigraphic quality number, group, stability, softening, promilographic maximum resistance, energy and loaf volume). With the usage of nutrient supply, most of the quality indicators increased, but only the $N_{90}PK$ dose made a significant improvement in the case of yield, water absorptions, promilographic energy, loaf volume (Figure 5.), average particle size, kernel weight and Hardness index, but further augmentation of fertilizer had

no observable effect. Revising yield, water absorption and loaf volume, it can be said that from the aspect of the baking industry the $N_{90}PK$ fertilizer treatment was enough to realize the yield and quality potential of the tested varieties.

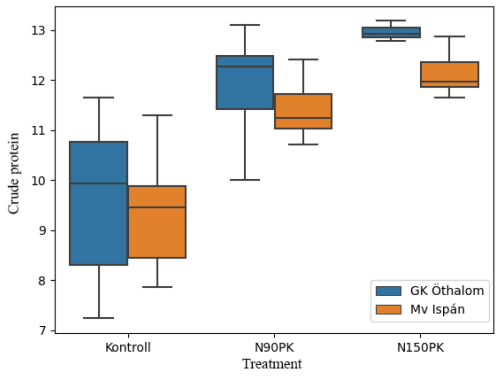


Figure 4. – Fertilizer and genotype effect on crude protein

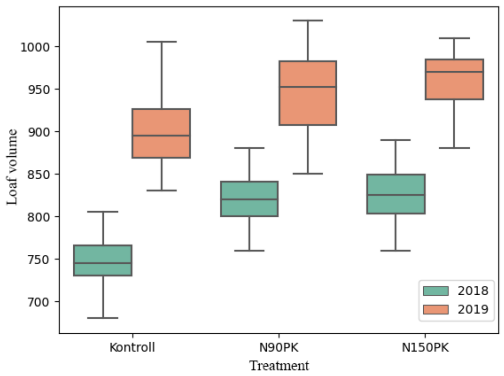


Figure 5. – Fertilizer and crop year effect on loaf volume

Furthermore, the measurement results suggested that fertilization played a decisive role in the development of post-harvest indices in the Hungarian wheat standard, like crude protein (Figure 4.), wet gluten, Zeleny index, valorigraphic quality number and group, stability, alveographic W and P/L, since even the $N_{150}PK$ dosage could significantly improve them. This is cardinal because there are years when up to half of the Hungarian wheat production is exported, where pricing and takeover are depending on these values. In the 2017/2018 crop year forecrop selection was very essential in the point of suboptimal (control) nutrient supply because in the case of yield, crude protein, dry gluten, Zeleny index, flour extraction, valorigraphic quality number, dough development time, stability, softening, promilographic ductility resistance, maximum resistance, energy, average particle size, alveographic W, P, L and P/L sweet corn significantly improved the results compared to sunflower, as it left a much more favourable condition. The effect of the studied agrotechnical factors on the quality of the gluten can be observed in the development of the gluten spread and gluten index values. The gluten index was greatly influenced by fertilization, crop year, and variety effects while the gluten spread was significantly modified by the forecrop effect instead of the variety. To summarize increment of fertilizers, high temperatures in April and May, large amounts of annual precipitation and sunflower as forecrop have a negative impact on the tenacity of gluten. The importance of variety selection should be highlighted since significant differences could be observed between gluten index, flour extraction,

valorigraphic water absorption, quality group, dough development time, stability, softening, promilographic ductility resistance, ductility, alveographic P, L, P/L, loaf volume and form ratio, starch damage, average particle size, kernel weight and diameter and Hardness index values of the studied cultivars. In general, comparing the 2 varieties GK Öthalom possessed better quality fertilizer use efficiency (NUE_{CP}) and quality parameters (Figure 4.) until then, Mv Ispán had better natural nutrient utilization property (+22.9%), NUE_Y ($N_{90}PK$: 32.62 kg/ha; $N_{150}PK$: 19.37 kg/ha) and yield (+31.7% in 2019). With the exception of the Zeleny index, only 1 sample complied with the quality criteria of the Hungarian wheat standard (I. class), namely the GK Öthalom variety (next to $N_{90}PK$ treatment, sweet corn as forecrop in 2019). The other samples were maximum II. class quality, which shows that none of the growing seasons was optimal for the vegetative and generative development of wheat. In addition, it is important to mention that, without fertilization, none of the samples complied with the requirements of II. class, in other words, these could only be used for feeding purposes.

3.2. Statistical analysis of the genotype testing experiment

In the case of the genotype testing part (n=120), I examined the effect of fertilization on the quality parameters (33) of 5 different winter wheat genotypes in 2 crop years. My further aim was to create a novel, innovative solution by these data in order to make it easier to understand and interpret large data sets within the framework of agristatistics through programmed visualization. To the best of my knowledge, no one in the past has used all of these options of Python program for this purpose in the field of agricultural science. In general, none of the years was favourable for the development of wheat. The ecological conditions of the first growing season (rich in rainfall, +177.3 mm annual precipitation) had a positive effect on the yield (+1553 kg/ha), flour extraction, gluten spread, loaf form ratio, kernel weight and diameter meanwhile, second crop year (with average precipitation) (Figure 3.) significantly improved the following indicators: alveographic P, W, valorigraphic quality group, stability, promilographic ductility resistance, maximum resistance, energy, ductility, gluten index, loaf volume (Figure 6.), starch damage and Hardness index, summarizing all the protein-linked parameters. During the comparative trial of the genotypes, I found also that the $N_{90}PK$ fertilizer dosage satisfied the nutritional requirements of the tested genotypes. However, nutrient treatments significantly improved 69% of the tested indices (22) compared to control samples, namely yield (+1804 kg/ha), crude protein (+2.37%), Zeleny index (+7.68 cm^3),

wet (+6.91%) and dry gluten, L (+30 mm), P/L, W (+63.6 x10^{-4}J), valorigraphic water absorption (+2.3%), quality number and group, dough development time (+1 min), stability (+2.5 min), softening, promilographic water absorption, ductility, gluten spread, gluten index (-12.3%), loaf form ratio and volume (+70 cm^3), average particle size and Hardness index (+7.9%).

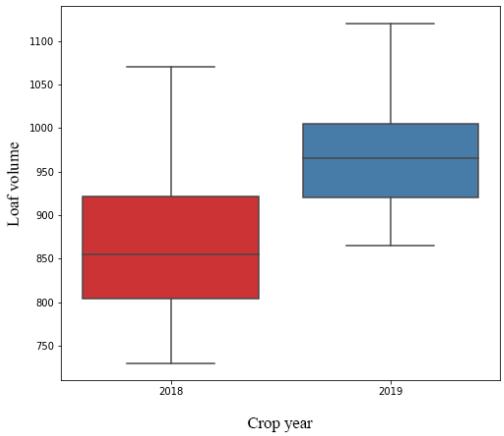


Figure 6. – Year effect on loaf volume

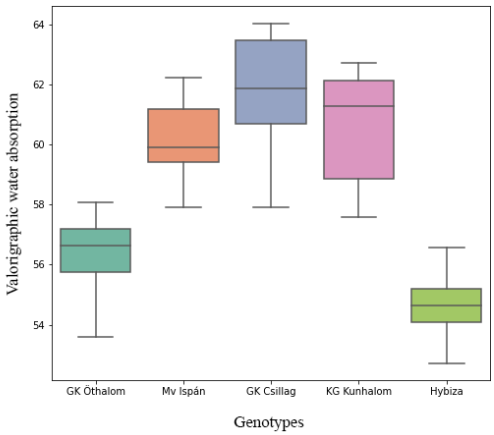
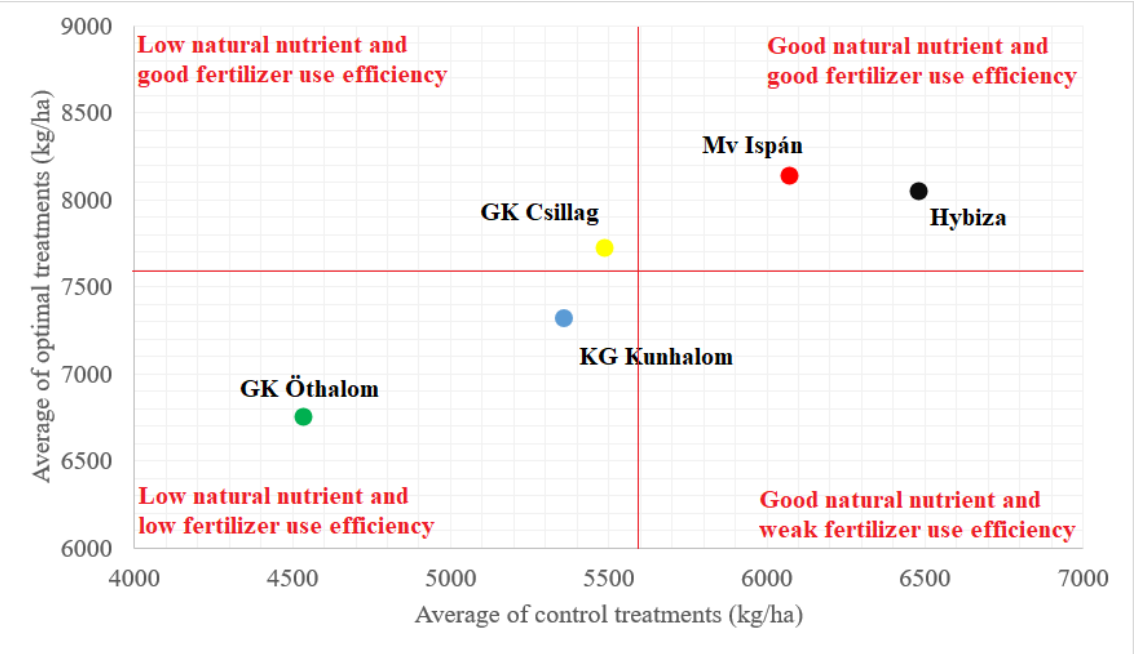


Figure 7. – Genotype effect on valorigraphic water absorption

In 2018 GK Öthalom, GK Csillag and Hybiza showed a statistically lower falling number, which can be explained by the extreme amount of precipitation. As I mentioned in the introduction, the average lifetime of the cultivated wheat varieties is constantly decreasing therefore, continuous testing of the latest registered genotypes is indispensable. One of the most important indicators of the agricultural sector is yield. In my experiment Hybiza (7457 kg/ha) and Mv Ispán (7346 kg/ha) performed better than GK Csillag (6862 kg/ha) and KG Kunhalom (6508 kg/ha), and significantly better than GK Öthalom (5702 kg/ha). According to *Balogh* (2009), Mv Ispán and Hybiza had good, GK Csillag and KG Kunhalom had average meanwhile, GK Öthalom had low natural nutrient and fertilizer use efficiency in terms of yield (Figure 8.).



*red lines mean experimental averages

Figure 8. – Natural nutrient and fertilizer use efficiency of the studied genotypes (idea of *Balogh, 2009*)

In contrast, KG Kunhalom and GK Csillag gave significantly higher protein-linked parameters, like crude protein, dry gluten, valorigraphic water absorption, quality group, dough development time, promilographic water absorption, ductility, maximum resistance, gluten spread and Hardness index. In the case of Zeleny index, wet gluten, alveographic L, P/L, valorigraphic quality number, stability, softening, loaf volume and average particle size, KG Kunhalom had significantly better values than the other genotypes. Mv Ispán variety was able to join the group of high-quality varieties in the case of valorigraphic water absorption and Hardness index. In addition, it is important to mention that Mv Ispán gave significantly higher starch damage, alveographic W and P values in comparison with the other genotypes.

Currently, the literature has little statistical data on hybrid wheat. Examining the only hybrid (Hybiza), it can be said that it had poor quality indicators and flour extraction, on the other hand, it had an exceptionally strong gluten structure, which had a counterproductive effect on the volume of the loaf volumes, despite the fact that the highest yield (9172 kg/ha) was produced by Hybiza during the experiment. These results suggest that Hybiza is basically unsuitable for the baking purposes, but can serve as an excellent feed source.

3.3. Pearson's correlation and regression analysis of the experiment

During the Pearson's correlation analysis (Figure 9.) a complex view of the relationships between the quality indicators of winter wheat flour (28) can be obtained, to mention some of them: there was a medium, positive correlation between alveographic P and starch damage (0.522**), crude protein and average particle size (0.711**), promilographic energy and alveographic W (0.578**); meanwhile there was tight, positive connection between promilographic ductility and alveographic L (0.835**).

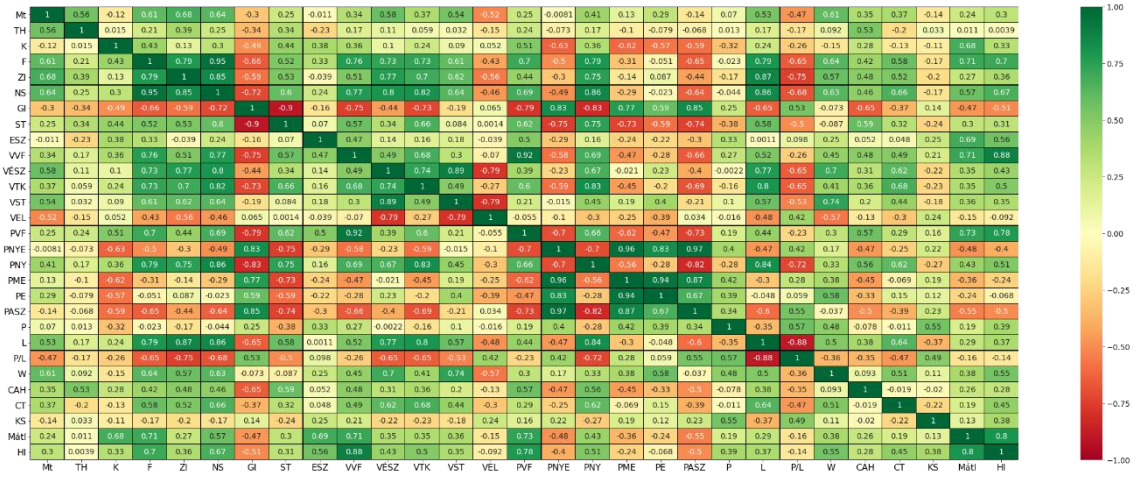


Figure 9. – The heatmap matrix of Pearson correlation analysis (genotype testing part)

Approached from a baker perspective, the most informative method is the baking test, as criteria of the current Hungarian market are embodied in the large-volume, open-structured products next to being E-number free. Loaf volume was in a moderate positive correlation with all the rheological and standard indicators, like crude protein (0.582**), wet gluten (0.665**), Zeleny-index (0.526**), valorigraphic quality number (0.625**), dough development time (0.68**), promilographic ductility (0.618**), alveographic L (0.644**) and W (0.513**). In addition to the loaf volume, the importance of the Hardness index should also be underlined, as it had a tight, positive relationship with the average particle size (0.807**), valorigraphic (0.883**) and promilographic water absorption (0.781**); in observable with crude protein (0.704**), wet gluten (0.668**), dough development time (0.503**), ductility (0.512**) and W (0.549**). The importance of the crude protein determination should be highlighted since 64% of the measured parameters (28/18) were at least in moderate correlation. The gluten index as a relatively recent quality indicator did not show a significant and practically usable interaction with the studied rheological and technofunctional parameters thus, it is not recommended for predicting the baking potential. At the same time, it is perfectly suitable for the

substitution of gluten spread which is a very time-consuming method. Several researchers tried to group the wheat flour-based on their gluten index value, in my case the optimal value was between 40-90% since these flours had the biggest-volumed loaves.

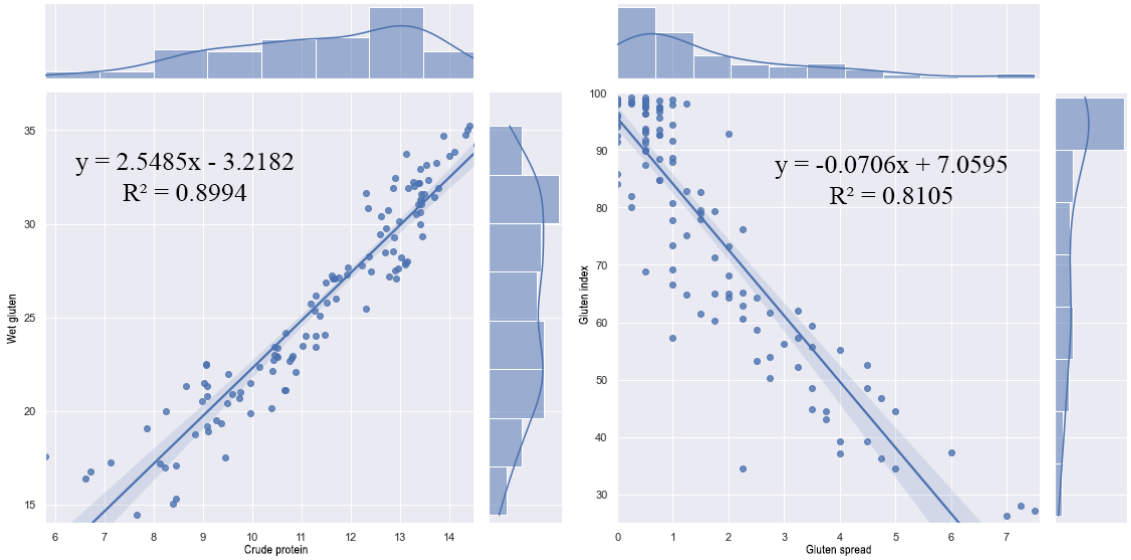


Figure 10-11. – Linear regression analysis of wet gluten and protein content on the left, gluten index and gluten spread on the right

The results of correlation (0.949**) and regression (R^2=0.899) (Figure 10.) between wet gluten and crude protein content, wet gluten content was used in the complexradars, because it is a faster method and can be done simultaneously by examining the gluten index. The results of correlation (0.899**) and regression (R^2=811) analysis between gluten index and gluten spread, gluten index was chosen in the complexradars, since it is a more precise method and can be done simultaneously by determining wet and dry gluten.

3.4. Multiple linear regression analyses of the genotype testing experiment to estimate loaf volume and valorigraphic water absorption

Using the results of Pearson's correlation analysis, I wanted to create an estimating equation for two important indicators (loaf volume and water absorption) by multiple linear regression analysis. I was able to estimate the loaf volume with the help of the Zeleny index, valorigraphic dough development time, the alveographic L and W value with the coefficient of determination R^2=0.554.

Loaf volume = 766.545 + (-4.92 * ZI) + (27.988 * DDT) + (1.332 * L) + (0.54 * W)

Valorigraphic water absorption (R^2=0.901) was estimated by using three quick methodical parameters: gluten index, Hardness index and NIR_P.

Valorigraphic water absorption = 52.6 + (-0.054 * GI) + (0.145 * HI) + (0.541 * NIR_P)

The usefulness of the loaf volume equation is underlined by the fact that the baking test is a very time-consuming method, requiring high precision and amount of wheat sample. Meanwhile, the advantage of the valorigraphic water absorption model is that it helps to approximately determine the water uptake to achieve a dough with a consistency of 500 VU.

3.5. Description of the Complexradars

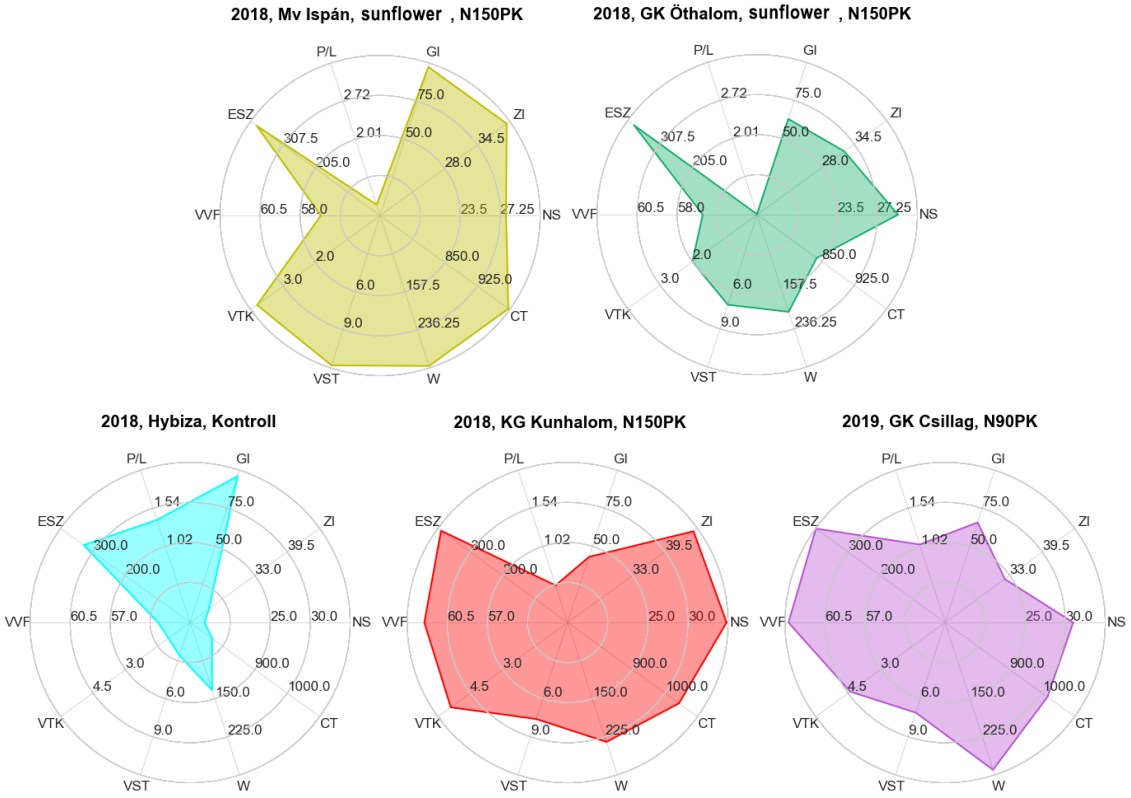


Figure 12. - Comparison of some complexradars of the experiment

In the 21st century, next to the simple communication of data, rapid and clear visualizations are becoming increasingly important therefore, I managed to create a highly informative and illustrative visualization, the complexradar, which analyse the effect of different factors by using the results of the two experiments, where the most important quality properties of the tested samples can be easily compared by 10

parameters (wet gluten, gluten index, Zeleny index, falling number, dough development time, stability, water absorption, loaf volume, W and P/L) to quickly get a complex view of a given wheat flour's quality potential (Figure 12.)

3.6. Principal component analysis of the quality parameters

Using the results of the two experiments, I also performed two principal component analyses to get to know the interactions between the studied quality attributes. During the 1st analysis, I studied the standard indicators (15), where I defined two main components: 1) "protein-linked parameters", which was essentially related to the crude protein, wet and dry gluten, NIR_{WG}, NIR_{CP}, Zeleny index, gluten index, gluten spread and Hardness Index; 2) "kernel hardness-linked parameters" since it correlated significantly with the Hardness index, kernel weight, kernel diameter, starch damage, falling number and average particle size.

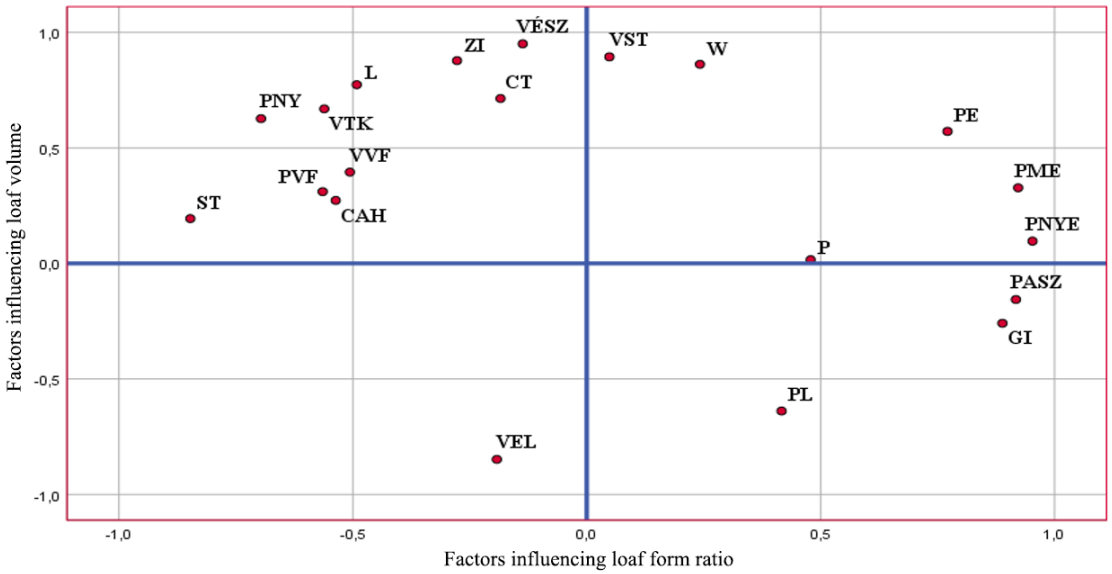


Figure 13. – Principal component analysis with R&T parameters

During the second analysis, rheological and technofunctional indicators (20) were included. I also found two principal components: 3) "factors influencing loaf form ratio", because it had a significant correlation with loaf form ratio, promilographic ductility resistance, ductility, maximum resistance, ratio, energy, water absorption, gluten index, gluten spread, valorigraphic water absorption and dough development time; 4) "factors influencing loaf volume", since it correlated observably with loaf volume, alveographic W, P/L and L, promilographic energy, ductility, valorigraphic quality number, stability, softening, dough development time and Zeleny index (Figure 13.)

3.7. Comparison of the experimental results of the genotype testing part with the Hungarian wheat standard

The quality parameters of the genotype experimental part with the requirements of the Hungarian wheat standard (MSZ 6383:2017) were compared. It was found that in the case of crude protein, wet gluten and Zeleny index only KG Kunhalom (in 2018), while in the case of valorigraph quality group and stability only GK Öthalom (in 2019) was able to achieve premium class. Studying alveographic W, GK Öthalom, GK Csillag and Mv Ispán gave premium quality several times in 2019. 94% of the samples in terms of falling number and 39% of the samples in the case of water absorption gave premium quality. There was no significant difference between the two nutrient treatment doses. With the exception of Hybiza, the other wheat varieties were at least II. class. Examining the hybrid, it can be seen that Hybiza could produce only occasionally milling quality in the case of quality attributes.

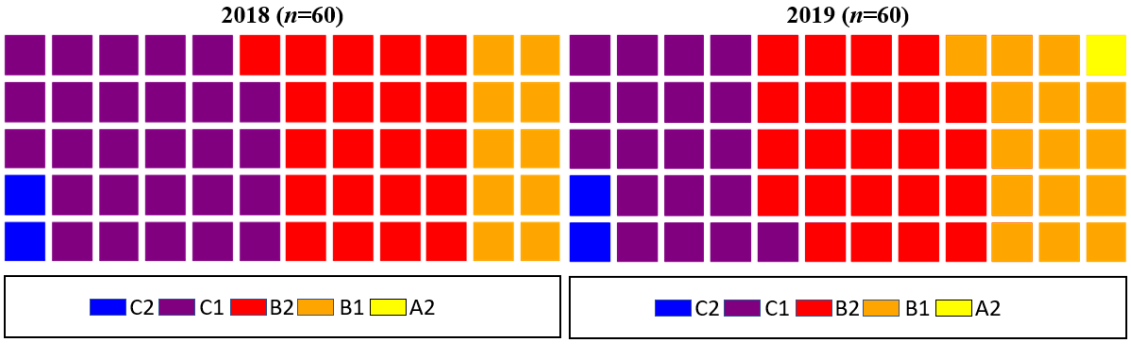


Figure 14. – Comparison of the valorigraphic quality groups in 2018 and 2019 with waffle diagrams (genotype testing part)

3.8. Summary

It should be noted as an important result that the waffle diagram for the valorigraphic quality group (Figure 14.), the joint diagram for the regression analysis, the heatmap for the Pearson's correlation analysis and agroecological values, the complexradar for the complex quality testing proved to be very informative visualizations in the field of agristatistics furthermore, in my opinion, they have a great potential even in other scientific fields too. Summarizing the results of my scientific work, great emphasis should be put on the selection of growing condition adapted varieties and genotype-specific nutrient supply to avoid over-fertilization but to maximize both yield and quality. Growing site optimized agrotechnics is also a key issue to mitigate the effects of the increasing biotic and abiotic stress factors. In addition, I believe that my research

can contribute to widen the knowledge of standard and less researched wheat quality indicators and the correlations that can be observed between them.

4. New and novel scientific results

1) Based on my scientific results, the $N_{90}PK$ fertilizer dosage was enough to realize the yield and quality potential of the studied wheat genotypes on calcareous chernozem soil type. The further increase of nutrient supply did not cause a statistically provable improving effect. The exceptions were the following: crude protein, wet gluten, Zeleny index, valorigraphic quality number and group, stability, alveographic W and P/L, which even $N_{150}PK$ treatment could significantly improve during the forecrop experiment.

(2) I have found that, the new genotypes, namely Hybiza and Mv Ispán owned significantly better yield potential, natural nutrition and fertilizer use efficiency compared to older varieties. However, KG Kunhalom and GK Csillag were able to achieve the best quality.

(3) Using multiple linear regression analysis, I have created mathematical model equations to estimate loaf volume and flour water absorption. I used Zeleny index, valorigraphic dough development time, alveographic L and W for the model of loaf volume, while gluten index, Hardness index and crude protein was used for water absorption.

(4) Next to 5 genotypes, 3 nutritional treatments and 2 breeding years during the Pearson's correlation analysis I have experienced that the loaf volume - which is one of the most important indices for the baking industry – was in moderate, positive correlation with crude protein, wet gluten, Zeleny index and several rheological parameters (valorigraphic quality number, dough development time, promilographic ductility, W and L). Based on these values, I have identified properties that are not suitable for replacing each other, so they can be potential variables of a mathematical model.

(5) Choosing 10 quality parameters (wet gluten, gluten index, Zeleny index, falling number, dough development time, stability, water absorption, loaf volume, W and P/L) I managed to create a new complexradar evaluation method for visual comparison of the wheat samples' quality characteristics and the effect of treatments.

5. Practical usability of the results

(1) Comparing the results of the two trials, taking into account economic considerations, the maximum yield and quality of the studied genotypes were achieved with the $N_{90}PK$ fertilizer dosage. Without fertilization, none of the samples complied with the requirements of the II. class standards, in other words, could only have been used for feeding purposes.

(2) Next to control nutrient treatment sweet corn as forecrop provided much more favourable conditions than sunflower on calcareous chernozem soil type in the case of yield, crude protein, dry gluten, Zeleny index, flour extraction, valorigraphic quality number, dough development time, stability, softening, promilographic ductility resistance, maximum resistance, energy, average particle size, alveographic W, P, L and P/L.

(3) I recommend KG Kunhalom and GK Csillag varieties next to the applied agrotechnics during the experiment for wheat production with baking use, since these genotypes performed the best in the case of post-harvest quality indicators (crude protein, dry gluten, valorigraphic water absorption, quality group, dough development time, promilographic water absorption, ductility, maximum resistance, gluten spread and Hardness index). These varieties had average yields (GK Csillag: 6862 kg/ha; KG Kunhalom: 6508 kg/ha). GK Öthalom (5702 kg/ha) as a classic variety had average quality, weak natural nutrient and fertilizer use efficiency. The best yields were given by the two latest genotypes (registered in 2015): Mv Ispán (7346 kg/ha) and Hybiza (7457 kg/ha) however, these owned the weakest quality parameters.

(4) The gluten index did not show significant and practically usable interaction with the studied rheological and technofunctional parameters thus, it is not recommended for predicting the baking potential. At the same time, it is perfectly suitable for the substitution of gluten spread which is a very time-consuming method, since it was in tight, negative correlation with it.

(5) The hardness index as a rapid method indicator is perfectly suitable for predicting the quality potential of the studied wheat samples since it had a tight, positive relationship with the average particle size, valorigraphic and promilographic water absorption; in observable with crude protein, wet gluten, dough development time, ductility and W.

(6) Less-known and used Matplotlib and Seaborn library of Python program is exceedingly suitable for visualization of large data sets in the field of agristatistics, like waffle diagram for the valorigraphic quality group, the joint diagram for the

regression analysis, the heatmap for the Pearson's correlation analysis and agroecological values and complexradar for complex quality assessment. Besides that, I created an extremely informative visualization, the complexradar which is able to compare simply the quality parameters of different samples with the help of 10 indices (wet gluten, gluten index, Zeleny index, falling number, dough development time, stability, water absorption, loaf volume, W and P/L).

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7. Publication list

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List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (1)

1. **Magyar, Z.**, Pepó, P., Bakos, T., Gyimes, E.: Az eltérő agrotechnikai faktorok hatása a búzaliszt próbacipós és egyéb minőségi paramétereire.
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3. Gyimes, E., Csercsics, D., **Magyar, Z.**: Effect of short term storage on wheat quality parameters.
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4. **Magyar, Z.**, Pepó, P., Gyimes, E.: Effects of agrotechnical factors on the quality and quantity of yield in winter wheat production.
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