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Comprehensive study on wheat flour quality attributes as influence by different agrotechnical factors

Z. Magyar[1,*], P. Pepó[1] and E. Gyimes[2]

[1]University of Debrecen, Kerpely Kálmán Doctoral School, Böszörményi street 138, HU4032 Debrecen, Hungary
[2]University of Szeged, Faculty of Engineering, Mars square 7, HU6724, Szeged Hungary
[*]Corresponding author. magyarzoltan93@gmail.com

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Abstract. The present polyfactorial long-term experiment was conducted to determine the role of different agrotechnical factors, like fertilization, forecrop, year and cultivar on the quality and yield attributes of a classical and a modern winter wheat genotypes. The research gives a complex view of the alteration of the most quality parameters (32) that are rarely done together in a single experiment (*n* = 96). All the studied factors had a significant effect on some tested properties. First growing season with fair water supply was beneficial for yield (+21.7%) however, the 2nd one with mild weather in spring and average annual precipitation was favourable for quality parameters (HFN: +3%, GI: +19%, GS: -51%, DDT: +22.4%, ST: +24.6%, DS: -14%, PDR: +37.6%, PD: +6%, PMR: +51.5%, PE: +52.7%, W: +25.8%, LV: +16.3%, HI: +13.3%). The optimal fertilizer demand of the different parameters varied to realize the potential of the varieties ($N_{90}P_{68}K_{80}$ for Y, VWA, PWA, PMR, PE, LV, Mavg, KW and HI; meanwhile $N_{150}P_{113}K_{133}$ for CP, WGC, ZI, VQN, ST, W and P/L). In the case of suboptimal nutrient supply, the effect of fore crops was significant (Y, CP, DGC, ZI, FE, VQN, DDT, ST, DS, PDR, PMR, PE, Mavg and all alveographic values). Comparing the varieties, GK Öthalom had better fertilizer response attribute (NUE_{CP}) and quality parameters, till then Mv Ispán possessed significantly better natural nutrient utilizing property (+22.9%), NUE_{Y} and yield (+31.7% in 2019). Summarizing the results, there is a need to put great emphasis on the selection of adapted cultivar and variety-specific agrotechnology practices, also these data contribute to a better understanding of the relationships between the quality parameters.

Key words: wheat flour quality, agrotechnical factors, yield, baking quality, fertilization.

Used abbreviations: Yr: year; Cv: cultivar; Fc: forecrop; Tr: treatment; FE: flour extraction rate; VWA: valorigraphic water adsorption; VQN: valorigraphic quality number; VQG: valorigraphic quality group; DDT: dough development time; ST: dough stability; DS: dough softening; GI: gluten index; WGC: wet gluten content; DGC: dry gluten content; GS: gluten spread; HFN: Hagberg falling number; LFR: loaf form ratio; LV: loaf volume; PWA: promilographic water adsorption; PDR: promilographic ductility resistance; PD: promilographic ductility; PMR: promilographic maximum resistance; PE: promilographic energy; P: alveographic tenacity; L: alveographic extensibility; P/L: ratio of tenacity and extensibility; W: alveographic deformation work; SD: starch damage; ZI: Zeleny index; Mavg: Malvern average (particle size distribution); CP: crude protein; HI: hardness index; KD: kernel diameter; KW: kernel weight;

NIRP: NIR crude protein; NIRWG: NIR wet gluten content; PSD: particle size distribution; VU: valorigraphic unit; PU: promilographic unit.

INTRODUCTION

Wheat flour is playing an unquestionably important role in our daily diet (Shewry & Hey, 2015), since it is the basic material of many industries, like baking, confectionery and pasta. The continuously increasing demands have led to the current challenge of agriculture, namely improving yield sustainably without exploiting the environment (Hawkesford et al., 2014). Another urgent problem is the frequency of abiotic stresses (Guzman et al., 2016), like temperature over 40 °C during grain filling period and the distribution and the amount of precipitation (Kong et al., 2013), which indicates that modern wheat cultivars have to possess good stress and disease tolerance ability next to proper yielding and quality attributes (Tayyar, 2010). In 2019, 24% of global wheat production was sold in international trade (OECD, 2019). The sales price of the exported wheat is determined by quality parameters of the given batch (Budai & Fükő, 1996). Hungary is traditionally a high-quality wheat growing country long ago (Bedő et al., 2018), which is also presented in the complexity of the national wheat standard (Table 1). In the case of growing wheat to export, every country has its quality standard that has to be taken into account. For instance, in Hungary, farinograph and valorigraph (QN) are one of the most substantial methods, in England starch damage, meanwhile in Italy P/L value, in France, South America, Portugal, Spain and Bosnia W value. In the past, the opinion of the researches changed a lot about which parameter or method is the most informative: VQN and HFN (Pollhamer, 1981); baking test (Markovics, 2001); VQN (Diósi et al., 2015); HFN, VWA, W and dough ductility (Huen et al., 2018). Wheat quality is excessively complex (Massaux et al., 2008), also it is impossible to define it with only one parameter. The quality parameters of wheat can be divided into two major groups: 1) chemical properties, like protein and wet gluten content, sedimentation value (Pasha et al., 2010); 2) physical ones, like colour, shape, weight and kernel hardness (Szabó et al., 2014), these attributes determine together the milling and baking value.

Table 1. Hungarian wheat standard (MSZ 6368:2017)

Parameters	Premium	I. class	II. class	
Crude protein	14.0	12.5	11.5	%
Wet gluten content	34	30	26	%
Hagberg falling number (min)	300	250	220	s
Zeleny index	45	35	30	mL
Valorigraph quality group	A	B	B	
Valorigraph water absorption	60	55	55	%
Stability	10	6	4	min
W	280	200	150	10^{-4} J
P/L (max)	1.0	1.5	1.5	

The quality of wheat is a genetically coded characteristic, although it is primordial to choose the right agronomy practice for realizing its yield and quality potential. These attributes can be greatly affected by forecrop, which is favourable if it does not exploit the nutrient and water supplies of the soil (Ragasits, 1998). Forecrop can influence significantly the yield in the case of control nutritional treatment and drier growing seasons, but fertilizing can mitigate these differences (Pepó, 2010c). The more unfavourable ecological conditions are left behind by a preceding crop, the greater economic investments are needed to be performed to create the adequate, basic conditions for growing good quality crop (Hajdu, 1977). In the 3-year experiment of Stoeva & Ivanova (2009), next to average fertilization, there was no observable difference between sunflower and maize as a forecrop considering WGC, LV, quality number and sedimentation value. Maize is an acceptable forecrop, but the earliness of its harvest is a substantial factor because of the appropriate preparatory works (Koltay & Balla, 1982). In Hungary, the growing area of sweet corn increased four-fold in the last 3 decades (HCSO, 2020). In addition to this, Hungary gives the one-fifth of European sunflower production (HNCAE, 2017).

Nagy & Pepó (2015) summarized the results of their 10 years long experiment, the yield surplus could be attributed to 50% fertilizing, 28% preceding crop, 16% pest control and 4% cropping year. In addition to this, Pepó & Sárvári (2011) concluded that the quality of wheat was influenced by 27% cultivar, 22% year-effect, 8% forecrop and 20% fertilizing. The 480–550 mm optimal water demand of wheat is considered moderate in accordance with other crops (Uthayakumaran & Wrigley, 2017). The utilization of fertilizers is influenced by water supply. In the experiment of Pepó (2010a) the yield surplus was 0.9–2.1 tonne ha^{-1} in droughty seasons, till then this value was 3.6–4.3 tonne ha^{-1} in average seasons. Lack of available water in autumn and spring can suppress early growth, stem elongation and fertilization (Pepó & Sárvári, 2011). In the study of Pepó (2010b), 1 mm precipitation induced 13.2 kg in the case of control treatment, meanwhile 20.7 kg next to optimal fertilization. In rainy seasons the grain filling period can be lengthened, which has a positive effect on yield (Gooding et al., 2017). In spring, rapid warming has a detrimental effect on tillering, until then the high temperature can worsen the grain filling period (Tayyar, 2010; Pepó & Sárvári, 2011; Szabó et al., 2017).

One of the most vital agrotechnics is proper nutritional supply, which can be achieved by fertilization (Győri & Győriné, 1998). Discussed by Nagy & Pepó (2015), in a given season the difference between two varieties can be 3 tonne ha^{-1} next to the same agronomic practice. The usage of fertilizers is influenced by nutrient reactionary properties (Pepó, 2011). Cultivar-effect significantly affected VQN, VWA, DDT, DS, WGC, CP, GI, ZI, LV, HFN, FE and SD parameters (Lukow & Vetty, 1991; Kovács, 1992; Panozzo & Eagles, 2000; Tanács & Gerő, 2003; Masauskiene & Ceseviciene, 2005). According to Borghi et al. (1995), nitrogen fertilizer has a decisive influence on the baking quality of wheat. The crude protein content is determined fundamentally by the genetically potential of the grown wheat genotype and the available nitrogen supply in the soil (Fowler, 2003). Above a certain threshold, increasing fertilizer dosage does not improve statistically yield and quality of winter wheat. This threshold was 210 kg ha^{-1} in Ying et al. (2017), 180 kg ha^{-1} N in Walsh et al. (2018) and Kovács (1992) and 168 kg ha^{-1} N in Shi et al. (2007) researches. The optimal N fertilizer dosage is between 120–150 kg ha^{-1}, recommended by many researchers (Kovács, 1992; Montemurro et al., 2007; Horváth et al., 2014; Asthir et al., 2017). In practice, a smaller amount of fertilizer is needed to maximize yield than realizing quality potential (Pepó, 2010c), for instance, in the research of Garrido-Lestache et al. (2004) the optimal N fertilizer dosage was 100 kg ha^{-1} for yield and 150 kg ha^{-1} for crude protein. Calculating optimal fertilizer dosage: soil type, preceding crop, variety and nutrient supply of soil have to be taken into account (Bicskei, 2008). According to Gugava & Korokhashvili (2018), 40–50% of the applied fertilizer is actually taken up by crops, the rest is leached out, evaporated or mineralized, this is why the timing of fertilizing is so substantial. Nitrogen fertilization increased significantly CP (Rao et al., 1993), WGC (Litke et al., 2018), water absorption (Kovács, 1992), DDT (Linina et al., 2014), quality number (Pollhamer, 1973) LV, yield, GI (Massoudifar et al., 2014), sedimentation value (Linina & Ruza, 2012), W, P/L (Garrido-Lestache et al., 2004), kernel hardness (Guarda et al., 2004), starch damage, DGC, ST, PSD (Cho et al., 2018) and P (Matuz et al., 2007), decreased DS and extensographic extensibility (Wooding et al., 2000), and worsened gluten spread and LFR (Pollhamer, 1965), but did not affect flour extraction rate (Cho et al., 2018). It must be emphasized that high wet gluten content is not equal with good gluten quality (Curic et al., 2001). Fertilizer dosage was in tight positive correlation with crude protein and wet gluten content (Masauskiene & Ceseviciene, 2005; Eser et al., 2017). Nitrogen fertilization can affect significantly the ratio and the number of gluten proteins (Wieser & Seilmeier, 1998), therefore the baking test volume and the gluten spreading as well (Pollhamer, 1973).

According to Chantret et al. (2005) kernel hardness is an inherited characteristic, and it can determinate damaged starch content, flour extraction rate, PSD and water absorption (Eliasson & Larsson, 1993; Manley, 1995). Particle size distribution is influenced by kernel hardness and milling technology, moreover the harder the wheat is, the greater the PSD will be after milling. Also, smaller PSD results in better water absorption, because of the increased surface (Preston and Williams, 2003). HFN can be significantly modified by the effect of cultivar and year (Gerő & Tanács, 2003).

Gabriel et al. (2017) pointed out that, defining crude protein is not enough to determine the quality potential of a flour batch, because over 12% CP content, the correlation between loaf volume and crude protein was not significant in their experiment, so high CP does not mean loaf with big volume in every case. The real quality value of wheat flour is expressed during processing (Pollhamer, 1981), which can be predicted by testing samples with different rheological methods, like alveograph, valorigraph or farinograph, extensograph or promylograph. Using these techniques, kneading properties, water absorption, strength and extensibility of dough can be prognosticated. Discussed by Preston et al. (1987), P was in a significant relationship with water absorption and starch damage. Sipos et al. (2007) concluded that L was in tight correlation with VQN, WGC, CP and extensibility; meanwhile, W was in a strong relationship with CP and WGC. Loaf volume was in a significant relationship with CP, DDT and ST (Cho et al., 2018).

Next to the same agronomy practice and cultivar, the yield can differ even more than 4–5 tonne ha^{-1} because of the ecological factors (Pepó, 2010b; Mohammed et al., 2013). Furthermore, Fuertes-Mendizábal et al. (2010) submitted that, next to the selection of proper variety, ecological factors can significantly influence CP content. Year-effect significantly affected WGC (Zecevic et al., 2013), HFN (Johansson, 2002), KW, FE, sedimentation value, water absorption (Muchová, 2003), LV, ST (Koppel & Ingver, 2010), CP, gluten index (Masauskiene & Ceseviciene, 2005), Hardness index, KW (Guarda et al., 2004). This opportunity brings up the most critical question for the farmers every year: sow the same variety like the last season, or experimentalize a new one in the hope for better yield and quality. Year and fertilizing significantly affected W in the study of Tóth et al. (2005).

It is estimated that, in the next 20–30 years, the demand for wheat will double due to the rapidly increasing population. This fact can cause serious problems in terms of the utilization of soils, therefore the knowledge of currently used agrotechnics, like water productivity and fertilizing has to be widened, recommended by Spiertz & Ewert (2009). In Hungary, the number of growable cultivars exceeded 150, thus the average lifetime of varieties are maximum 5–7 years (Pepó & Sárvári, 2011). These facts valorise the value of the long-term experiments and the continuous testing of the recently registered cultivars. Thus, the object of this paper was to study the effect of different agrotechnical factors such as fertilization, forecrop, year and cultivar on the quality and yield attributes of a classical, widely-used and a modern, currently available winter wheat genotype. In addition, the comprehensiveness of the experiment can help to understand the relationship between the parameters of the common and infrequently-used methods.

MATERIALS AND METHOD

The experiment was done at Látókép Experimental Farm (University of Debrecen) in two consecutive growing seasons (2017–2018, 2018–2019) in split-split plot design. The long-term experiment was set up in 1983, 15 km from Debrecen (NL 47°33', EL 21°27'). The area belongs to calcareous chernozem and loam type and has medium humus content: 2.7–2.8% (humus layer: 80–100 cm), medium P (0–25 cm: 133.4 ppm; 25–50 cm: 48.0 ppm; 50–75 cm: 40.4 ppm; 75–100 cm: 39.8 ppm) and K (0–25 cm: 239.8 ppm; 25–50 cm: 173.6 ppm; 50–75 cm: 123.0; 75–100 cm: 93.6 ppm) supply and neutral pH (6.46). The forecrops were sweet corn and sunflower because of their substantial role in Hungarian agriculture. The effect of three fertilizer levels (control, $N_{90}P_{67,5}K_{79,5}$; $N_{150}P_{112,5}K_{132,5}$) was tested in 10 m^2 plots in 4 repetitions to understand the influence of medium and over-fertilization (Table 2).

Table 2. Fertilizing treatments of long-term experiment

Treatments	Time of application	N	P	K
		(kg ha^{-1})		
Ø (Control)	-	-	-	-
3 (N_{90}PK)	autumn (basic fertilizing)	45	67.5	79.5
	spring (top dressing)	45	-	-
5 (N_{150}PK)	autumn (basic fertilizing)	75	112.5	132.5
	spring (top dressing)	75	-	-

The 50% of N and the whole amount of the P and K were applied in autumn (02.10.2017; 20.09.2018, respectively), the remaining 50% of the N fertilizer was applied in spring as top dressing (12.04.2018; 20.03.2019, respectively). Following winter wheat genotypes were tested: GK Öthalom, a classic Hungarian wheat cultivar (year of registration: 1985, awnless head and early maturity type, improve quality, A_1–A_2 class, breeder: GabonaKutató Kft) and Mv Ispán, a modern cultivar (year of registration: 2015, awned head and medium maturity type, good baking quality, A_1–B_1 class, breeder: Marton Genetics).

First, the samples were treated by SLN Pfeuffer sample cleaner, then conditioned to 15.5% moisture content, lastly milled into flour with Brabender Quadrumat Senior laboratory mill (MSZ 6367/9-1989). Crude protein (Kjeldahl method), wet gluten content (ISO 21415-2:2015), Zeleny index (MSZ EN ISO 5529), dry gluten content (ISO 21415-4:2006), gluten index (ISO 21415-2:2015), falling number (ISO 3093:2009), starch damage (ISO 17715:2013), baking test (MSZ 6369/8-1988), valorigraph (MSZ ISO 5530-3:1995), promylograph and alveograph (ISO 27971:2015) parameters were defined at the Institute of Food Engineering, University of Szeged. The method of Promylograph is very similar to extensograph, where a 500-consistency dough is made, and after 45–90–135' resting time the moulded doughs are torn by a metal hook, till then the load on the dough is recorded. With this method dough stretchability can be tested.

Calculating nitrogen use efficiency (NUE) values, the following equitation's were used:

$$\frac{Yield_N - Yield_C}{A_N} = NUE_Y \qquad \frac{CP_N - CP_C}{A_N} = NUE_{CP}$$

where $Yield_N$ = fertilized yield; $Yield_C$ = control yield; A_N = amount of *N*; CP_N = fertilized *CP*; CP_C = control *CP*.

For processing the results of the measurements, R studio 3.6.1 version was used. For arranging and filtering the data, dplyer package (Wickham et al., 2019) was utilized. One-way ANOVA with least significant difference (*LSD*) post-hoc tests on $P > 0.05$ significance level of agricolae package (Mendiburu, 2019) and Pearson's correlation analysis of SPSS Statistics 25 were performed. According to Tóthné (2011) there are very tight, tight, medium and loose correlations if the correlation coefficient is between 0.9–1, 0.75–0.9, 0.5–0.75 and 0.25–0.5, respectively. For graphical representation Seaborn 0.9.0 library (boxplot chart) of Python 3.7 version was used.

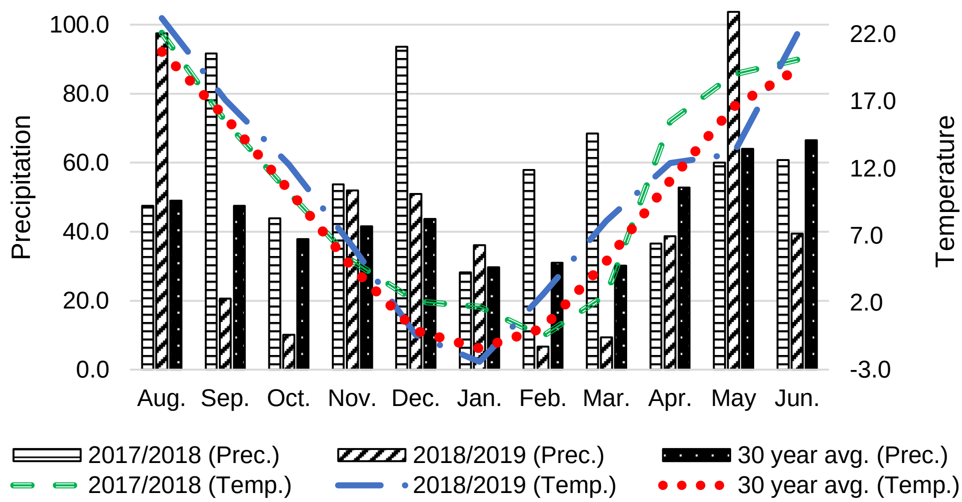

Figure 1. Agrometeorological parameters of the two growing seasons.
Season 1: Sowing date: 04.10.2017 – Harvest date: 05.07.2018;
Season 2: Sowing date: 05.10.2018 – Harvest date: 09.07.2019.

The first season was rainy (total precipitation: 642.4 mm), till then the second was normal (465.1 mm), but in both seasons (2017–2018: 10.3 °C; 2018–2019: 10.4 °C) the average temperature was higher with 1 °C, compared to 30-year average (9.3 °C) (Fig. 1), which correlates well with the global warming trends, like rising temperature, extreme conditions and less precipitation. To summarize, the weather of both growing seasons was unfavourable for the vegetative and generative development of wheat plants.

RESULTS AND DISCUSSION

According to our results, all the 4 factors had significant effect on some studied parameters. Main attributes varied between: 7.2–13.5% (CP); 14.87–32.46 (WGC); 287–420 s (HFN); 19.4 (C2)-70.7 (A2) (VQN); 105.9–329.9 (W); 680–1,030 cm^3 (LV), 2,714–8,871 kg ha^{-1} (Y), which are presented in the Table 3. and Table 6.

Table 3. Effect of the studied factors on classical parameters (Debrecen, Hungary)

Yr	Cv	Fc	Tr	Y (kg ha^{-1})	CP (%)	ZI (cm^3)	WGC (%)	DGC (%)	GS (mm)	HFN (s)	NIRP (%)	NIRWG (%)
2018	GK Öthalom	Sweet corn	Ø	5,795	8.79	20.4	16.65	5.91	0.4	374	8.44	16.86
			$N_{90}P_{68}K_{80}$	7,216	12.04	32.4	25.19	8.90	1.0	356	12.65	27.14
			$N_{150}P_{113}K_{133}$	6,425	13.14	36.7	28.26	9.84	0.8	343	13.74	29.75
		Sunflower	Ø	3,610	7.47	15.6	16.65	5.79	0.6	365	7.07	12.86
			$N_{90}P_{68}K_{80}$	6,046	11.29	29.5	24.72	8.63	1.8	402	11.91	24.93
			$N_{150}P_{113}K_{133}$	7,821	12.45	32.5	29.24	10.25	2.9	390	12.91	27.48
	Mv Ispán	Sweet corn	Ø	6,806	9.55	25.9	20.68	7.10	1.4	382	10.38	19.91
			$N_{90}P_{68}K_{80}$	8,871	12.03	35.1	27.08	9.31	1.5	390	13.15	26.93
			$N_{150}P_{113}K_{133}$	8,505	12.84	38.2	28.82	9.91	1.1	387	13.81	28.60
		Sunflower	Ø	2,714	8.25	20.7	16.06	5.61	0.8	370	9.59	17.05
			$N_{90}P_{68}K_{80}$	8,710	10.90	31.5	24.80	8.45	1.4	377	12.28	24.61
			$N_{150}P_{113}K_{133}$	8,708	12.03	35.0	27.59	9.45	1.9	394	13.36	27.83
2019	GK Öthalom	Sweet corn	Ø	3,276	10.65	26.7	21.10	7.62	0.0	390	10.93	23.02
			$N_{90}P_{68}K_{80}$	5,202	12.61	34.3	30.36	10.94	0.7	396	13.23	28.73
			$N_{150}P_{113}K_{133}$	6,298	13.00	34.9	28.65	10.26	0.3	391	13.56	29.45
		Sunflower	Ø	3,285	11.07	31.4	22.59	8.11	0.3	378	11.90	25.84
			$N_{90}P_{68}K_{80}$	5,083	12.00	35.5	25.48	9.24	0.6	403	12.96	28.06
			$N_{150}P_{113}K_{133}$	5,650	12.94	40.4	27.83	10.05	0.7	391	13.87	29.98
	Mv Ispán	Sweet corn	Ø	5,335	9.66	25.8	20.21	7.01	0.3	384	10.77	21.30
			$N_{90}P_{68}K_{80}$	7,408	11.32	30.0	25.06	8.51	0.4	388	12.53	25.69
			$N_{150}P_{113}K_{133}$	7,154	11.80	32.2	27.29	9.35	0.7	393	13.11	27.26
		Sunflower	Ø	4,772	9.93	27.0	21.14	7.38	0.7	389	11.20	22.96
			$N_{90}P_{68}K_{80}$	6,380	11.04	30.1	24.82	8.60	0.9	380	12.40	25.68
			$N_{150}P_{113}K_{133}$	6,880	11.90	33.0	27.53	9.55	1.1	380	13.22	28.08
			$LSD_{5\%}$ (Yr):	1,451.1	0.64	2.41	1.79	0.63	0.26	7.86	0.71	1.80
			$LSD_{5\%}$ (Cv):	1,421.3	0.64	2.45	1.81	0.64	0.30	8.17	0.73	1.87
			$LSD_{5\%}$ (Fc):	1,513.3	0.64	2.45	1.80	0.64	0.29	8.16	0.73	1.87
			$LSD_{5\%}$ (Tr):	1,413.0	0.47	1.89	1.24	0.47	0.35	9.98	0.54	1.42

Fertilizing ($N_{90}P_{68}K_{80}$: 6,865 kg ha^{-1}; $N_{150}P_{113}K_{133}$: 7,180 kg ha^{-1}) increased (+53% and +61%, respectively) significantly the yield, compared to control samples (4,449 kg ha^{-1}), however in 2018 yields were higher (2018: 6,769 kg ha^{-1}; 2019: 5,560 kg ha^{-1}) with 21.7%, but this amount was not significant (Fig. 2), which was also reported by Pepó (2010a). The explanations were already concluded by Gooding et al.

(2017), namely precipitation during grain filling can observably improve yield. In 2018, considering only the control samples, sweet corn (6,301 kg ha^{-1}) gave significantly ($LSD_{5\%}$: 2,906.2 kg ha^{-1}) higher yield, compared to sunflower (3,162 kg ha^{-1}). In 2019, Mv Ispán (6,321.5 kg ha^{-1}) had significantly ($LSD_{5\%}$: 1,488.5 kg ha^{-1}) higher (+31.7%) yield in comparison to GK Öthalom (4,799 kg ha^{-1}). These results are in compliance with the findings of Pepó (2010c), who stated that the effect of forecrops can be significant in the case of control treatments, but these differences disappeared with optimal nutrient supply. In general, only $N_{90}P_{68}K_{80}$ dosage could improve significantly the yield, further increment of fertilizer had no observable effect, which confirms the findings of Kovács (1992), Garrido-Lestache et al. (2004), Shi et al. (2007), Ying et al. (2017) and Walsh et al. (2018). First growing season was a rainy one, this amended the yield compared to the 2nd one, which had average precipitation, thereby our results affirmed the observations of Tayyar (2010) and Gooding et al. (2017). Also, our results underlined the importance of variety selection, since the difference between cultivars can be significant next to the same agrotechnics.

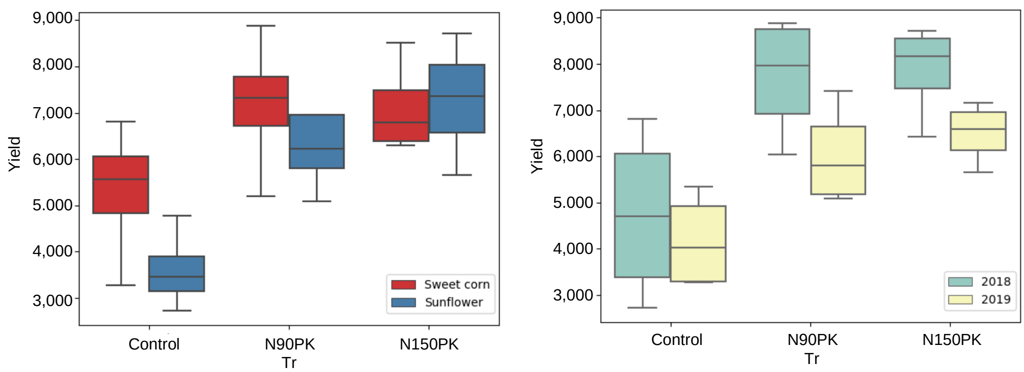

Figure 2. Effect of forecrops (left), year (right) and treatment on yield.

Table 4. shows the effect of different fertilizer doses on nitrogen use efficiency (NUE) in the case of the two most important post-harvest indicators, namely yield and CP. Several studies evaluated these parameters. Yield NUE was 8.2 kg ha^{-1} in the research of Lollato et al. (2019), meanwhile protein NUE was 0.025% in the study of Miceli et al. (1992) and 0.004% in the article of Lollato et al. (2019). Examining GK Öthalom, it can be said that, yield NUE decreased slightly with the increment of fertilizer, however studying Mv Ispán, it was significantly higher with the first dose ($N_{90}P_{68}K_{80}$: 32.62 kg ha^{-1}), but this difference disappeared in the case of $N_{150}P_{113}K_{133}$ dosage (19.37 kg ha^{-1}). Considering the crude protein NUE, GK Öthalom performed better in the case of both dosages ($N_{90}P_{68}K_{80}$: 0.028%; $N_{150}P_{113}K_{133}$: 0.023%), comparing to Mv Ispán ($N_{90}P_{68}K_{80}$: 0.022%; $N_{150}P_{113}K_{133}$: 0.019%). Comparing the varieties, GK Öthalom had better fertilizer response attribute (NUE_{CP}) and CP, till then Mv Ispán possessed considerably better natural nutrient utilizing property (+22.9%) and NUE_{Y}.

Table 4. Nitrogen use efficiency considering yield and crude protein

Cv	Tr	Yield		Crude protein	
		avg. (kg ha^{-1})	NUE	avg. (%)	NUE
GK Öthalom	Ø	3,992	-	9.50	-
	$N_{90}P_{68}K_{80}$	5,887	21.06	11.99	0.028
	$N_{150}P_{113}K_{133}$	6,549	17.05	12.88	0.023
Mv Ispán	Ø	4,907	-	9.35	-
	$N_{90}P_{68}K_{80}$	7,842	32.62	11.32	0.022
	$N_{150}P_{113}K_{133}$	7,812	19.37	12.14	0.019

Before performing the standard methods, the NIR measurements were executed to have a basic view of moisture, crude protein and wet gluten content. Both fertilizer doses (C: 10.03%; $N_{90}P_{68}K_{80}$: 12.64%; $N_{150}P_{113}K_{133}$: 13.45%) improved significantly NIR Protein. 2019 (12.47%) gave observably higher NIRP than 2018 (11.61%), but forecrops and cultivars did not differ. Studying only control samples in 2018, Mv Ispán (9.98%) had significantly ($LSD_{5\%}$: 1.02%) greater NIRP, than GK Öthalom (7.76%), but in 2019 GK Öthalom (13.72%) possessed higher ($LSD_{5\%}$: 0.21%) NIRP compared to Mv Ispán (13.16%) with $N_{150}P_{113}K_{133}$ treatment. This meant that, GK Öthalom had better fertilizer reactionary attribute, till then Mv Ispán possessed significantly better natural nutrient utilizing property. NIRWG showed similar trends like NIRP, 2019 (26.34%) gave significantly greater NIRWG values than 2018 (23.66%), also both nutrient treatments (C: 19.98%; $N_{90}P_{68}K_{80}$: 26.47%; $N_{150}P_{113}K_{133}$: 28.55%) increased significantly NIRWG, but forecrops and cultivars did not differ in general. Considering control samples in 2018, sweet corn (18.39%) improved observably ($LSD_{5\%}$: 2.8%) NIRWG values in contrast with sunflower (14.96%). In 2019, GK Öthalom (27.51%) produced significantly ($LSD_{5\%}$: 1.68%) better NIRWG than Mv Ispán (22.13%).

Scrutinizing the standard methods, there were no considerable differences between the years, forecrops and cultivars, but both fertilizer (C: 9.42%; $N_{90}P_{68}K_{80}$: 11.65%; $N_{150}P_{113}K_{133}$: 12.51%) doses increased significantly the crude protein. In 2018, studying the control samples, sweet corn (9.17%) gave observably higher CP, than sunflower (7.86%). In 2019, GK Öthalom (12.05%) owned significantly greater CP values (Fig. 3), compared to Mv Ispán (10.94%), as well as in the experiments of Rao et al. (1993), Masauskiene & Ceseviciene (2005) and Fuertes-Mendizábal et al. (2010).

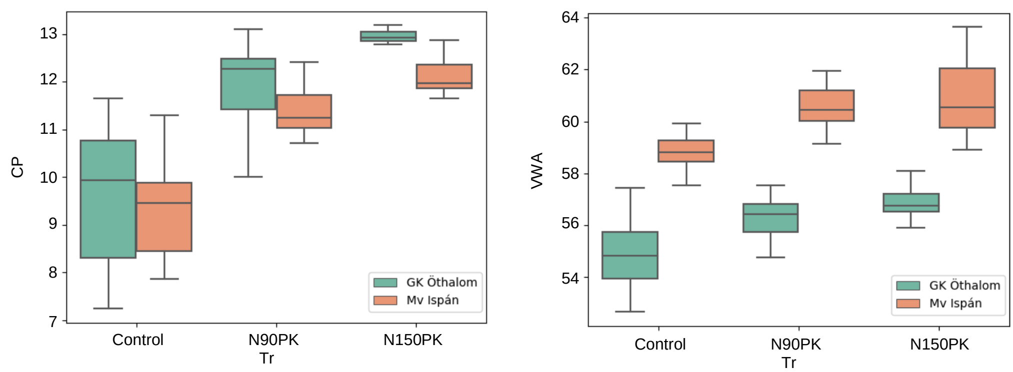

Figure 3. Effect of cultivars, treatment on crude protein (left) and water absorption (right).

Wet gluten content was significantly improved by fertilizing (C: 19.38%; $N_{90}P_{68}K_{80}$: 25.94%; $N_{150}P_{113}K_{133}$: 28.15%), like in the study of Litke et al. (2018), at the same time forecrop, year and cultivar did not affected WGC in general. Considering the effect of preceding crops, Stoeva and Ivanova (2009) got the same results. In 2019, in the case of $N_{90}P_{68}K_{80}$ dose, GK Öthalom (27.92%) had significantly ($LSD_{5\%}$: 2.59%) higher WGC, compared to Mv Ispán (24.94%). Dry gluten content showed similar results like wet gluten content in general, namely the fertilizing significantly affected the studied parameter (C: 6.82%; $N_{90}P_{68}K_{80}$: 9.07%; $N_{150}P_{113}K_{133}$: 9.83%). In 2019, in the case of control treatment, sweet corn (7.87%) gave observably greater DGC than sunflower (7.19%), also studying the results of $N_{90}P_{68}K_{80}$ and $N_{150}P_{113}K_{133}$ dose, GK Öthalom ($N_{90}P_{68}K_{80}$: 10.09%; $N_{150}P_{113}K_{133}$: 10.16%) owned considerably ($LSD_{5\%}$: 0.85%, 0.43%, respectively) higher values, than Mv Ispán ($N_{90}P_{68}K_{80}$: 8.56%; $N_{150}P_{113}K_{133}$: 9.45%). These results indicate that GK Öthalom had a better fertilizer reactionary property.

Both fertilizer dose (C: 24.19 cm^3; $N_{90}P_{68}K_{80}$: 32.29 cm^3; $N_{150}P_{113}K_{133}$: 35.37 cm^3) significantly improved Zeleny index, however there was no serious difference between the studied years, cultivars and forecrops. A similar conclusion was done by Linina & Ruza (2012), Stoeva and Ivanova (2009). In 2018 with control treatment, sweet corn (23.15 cm^3) as a forecrop gave significantly ($LSD_{5\%}$: 3.78 cm^3) higher ZI values than sunflower (18.15 cm^3). In 2019, GK Öthalom (33.86 cm^3) had significantly ($LSD_{5\%}$: 2.14 cm^3) higher ZI, compared to Mv Ispán (29.66 cm^3), also the samples with control treatment, grown after sunflower (29.21 cm^3) had significantly ($LSD_{5\%}$: 2.39 cm^3) greater Zeleny index, than sweet corn (26.24 cm^3).

Effect of fertilizing on gluten quality was reflected in change in the gluten index and gluten spread, where increasing fertilizer dosage (C: 95.5%; $N_{90}P_{68}K_{80}$: 83.42%; $N_{150}P_{113}K_{133}$: 80.24%) significantly weakened the gluten strength (GI), like in the study of Massoudifar et al. (2014). Also, the difference of the studied cultivars (GK Öthalom: 90.03%; Mv Ispán: 82.74%) was observable, like in the research of Masauskiene & Ceseviciene (2005). Interestingly, the findings of Masauskiene & Ceseviciene (2005) were affirmed, because year-effect significantly influenced the gluten index, namely in 2019 the GI was 93.91%, in contrast with 2018 it was just 78.86%, but forecrops had no visible effect. Scrutinizing the results of gluten spread, that can be observed, there was no difference between the cultivars, however 2018 (1.3 mm) gave significantly higher values, than 2019 (0.55 mm). Samples grown after sunflower (1.13 mm) had observably greater GS, compared to sweet corn (0.72 mm), also increment of fertilizer (C: 0.56 mm; $N_{90}P_{68}K_{80}$: 1.04 mm; $N_{150}P_{113}K_{133}$: 1.17 mm) significantly augmented gluten spread, just like in the study of Pollhamer (1965). In 2019, Mv Ispán (0.68 mm) gave observably ($LSD_{5\%}$: 0.25 mm) higher GS values, than GK Öthalom (0.42 mm). To compile, increment of fertilizer, high temperature in April and May, large amount of annual precipitation and sunflower (exploitive) as preceding crop deteriorate significantly the gluten strength.

Studying the flour extraction rates, it can be seen that GK Öthalom (70.99%) had significantly higher FE values compared to Mv Ispán (69.16%), meanwhile fertilizing and forecrop had no considerable effect. Our results were in compliance with Chantret et al. (2005) and Cho et al. (2018). In 2018, sweet corn (72.86%) gave significantly ($LSD_{5\%}$: 0.89%) higher FE values, than sunflower (71.76%), also this difference was even greater in the case of control samples (sweet corn: 73.24%; sunflower: 71.02%).

Fertilizing, forecrop and cultivar did not affect the Hagberg falling number, however year exerted influence on the studied parameter, namely 2019 (388.5 s) gave significantly higher (+3%) HFN, compared to 2018 (377.3 s), which affirmed the statements of Johansson (2002) and Gerő & Tanács (2003).

Table 5. Effect of the studied factors on rheological parameters (Debrecen, Hungary)

				Valorigraph					Promylograph					Alveograph			
Yr	Cv	Fc	Tr	VWA (%)	VQN	DDT (min)	ST (min)	DS (VU)	PWA (%)	PDR (PU)	PD (mm)	PMR (PU)	PE (cm^2)	P (mm)	L (mm)	P/L	W (x10^{-4} J)
2018	GK Öthalom	Sweet corn	Ø	53.7	33.1	1.4	2.6	155	48.6	286	94	295	40	63.6	51.4	1.3	120
			$N_{90}P_{68}K_{80}$	56.4	44.8	2.0	7.1	130	49.5	374	118	455	70	64.5	94.3	0.7	208
			$N_{150}P_{113}K_{133}$	57.1	49.5	2.3	8.5	118	50.1	382	119	478	72	67.7	108.6	0.6	241
		Sunflower	Ø	53.8	22.7	1.0	2.3	195	47.8	211	103	214	32	73.9	36.6	2.0	108
			$N_{90}P_{68}K_{80}$	55.4	41.7	1.8	6.3	139	49.0	298	111	326	50	62.5	87.4	0.7	176
			$N_{150}P_{113}K_{133}$	56.4	45.9	2.0	7.1	134	48.8	286	113	315	49	62.0	101.2	0.6	201
	Mv Ispán	Sweet corn	Ø	58.2	34.8	1.1	3.1	145	51.1	370	98	395	52	89.7	52.4	1.8	167
			$N_{90}P_{68}K_{80}$	61.3	49.6	2.3	8.0	123	53.2	332	117	409	62	92.2	83.8	1.1	249
			$N_{150}P_{113}K_{133}$	61.8	54.8	2.5	8.8	108	53.7	361	124	448	73	95.9	87.1	1.1	272
		Sunflower	Ø	58.4	25.5	1.0	1.9	171	50.2	463	82	469	51	116.8	34.4	3.4	132
			$N_{90}P_{68}K_{80}$	61.1	44.2	1.6	6.4	131	52.5	401	108	458	64	109.5	60.6	1.9	238
			$N_{150}P_{113}K_{133}$	62.5	50.6	2.0	7.9	110	53.6	436	120	557	83	118.0	75.3	1.6	313
2019	GK Öthalom	Sweet corn	Ø	55.7	37.3	1.5	4.5	147	49.1	341	112	427	62	70.1	74.1	1.0	194
			$N_{90}P_{68}K_{80}$	57.1	59.6	2.6	11.3	88	49.4	482	127	658	104	82.9	97.2	0.9	283
			$N_{150}P_{113}K_{133}$	57.1	64.1	3.0	11.9	80	49.7	414	130	600	95	85.1	99.3	0.9	297
		Sunflower	Ø	56.1	47.9	2.1	7.1	116	49.0	555	107	669	91	91.2	71.5	1.3	227
			$N_{90}P_{68}K_{80}$	56.2	57.1	2.9	9.9	91	49.6	508	117	687	96	91.1	92.4	1.0	295
			$N_{150}P_{113}K_{133}$	56.7	64.9	3.8	11.8	75	49.6	546	133	785	128	81.7	102.9	0.8	311
	Mv Ispán	Sweet corn	Ø	59.1	32.7	1.4	3.0	160	50.6	481	97	519	66	93.0	47.3	2.0	169
			$N_{90}P_{68}K_{80}$	60.2	41.1	1.5	5.6	145	51.3	411	116	503	74	90.0	63.5	1.4	239
			$N_{150}P_{113}K_{133}$	59.7	47.4	2.0	7.0	123	51.1	397	125	529	83	97.1	86.2	1.1	285
		Sunflower	Ø	59.4	35.3	1.5	3.6	153	51.8	573	99	620	80	108.6	51.1	2.2	207
			$N_{90}P_{68}K_{80}$	59.7	41.8	1.5	4.7	130	51.6	546	103	630	84	107.7	67.2	1.6	257
			$N_{150}P_{113}K_{133}$	59.5	46.0	1.8	6.6	120	51.6	527	121	671	102	101.0	81.8	1.2	286
			$LSD_{5\%}$ (Yr):	1.00	4.44	0.29	1.21	11.84	0.69	34.3	5.49	43.9	7.33	7.17	9.23	0.27	23.45
			$LSD_{5\%}$ (Cv):	0.54	4.50	0.29	1.18	12.21	0.42	42.3	5.51	60.8	9.64	4.80	8.45	0.23	25.63
			$LSD_{5\%}$ (Fc):	1.00	4.61	0.30	1.24	12.45	0.69	41.9	5.57	59.8	9.59	6.95	9.18	0.26	25.76
			$LSD_{5\%}$ (Tr):	0.47	3.99	0.30	1.07	11.72	0.80	53.4	4.84	71.9	10.43	8.95	7.61	0.27	21.58

The relevant data given in Table 5, which subsume the results of the rheological methods. Valorigraphic water absorption was significantly increased by fertilizing compared to control samples (C: 56.79%; $N_{90}P_{68}K_{80}$: 58.42%; $N_{150}P_{113}K_{133}$: 58.85%), but forecrop and year had no influence on VWA. Moreover, Mv Ispán (60.07%) gave observably greater VWA (Fig. 3), compared to GK Öthalom (55.97%), which is in compliance with the results of Tanács & Gerő (2003). The findings of Tanács & Gerő

(2003) were affirmed, because GK Öthalom (47.39) had significantly better valorigraphic quality number than Mv Ispán (41.97). In addition to this, 2019 (47.93) gave observably higher VQN compared to 2018 (41.44), also increment of fertilizers (C: 33.67; $N_{90}P_{68}K_{80}$: 47.49; $N_{150}P_{113}K_{133}$: 52.89) increased significantly the quality number, but there was no difference between the studied preceding crops. In 2018, sweet corn (44.43) gave significantly ($LSD_{5\%}$: 5.89) better VQN than sunflower (38.45). Interestingly, in the case of $N_{150}P_{113}K_{133}$ dosage, in 2018, Mv Ispán (52.68) gave significantly ($LSD_{5\%}$: 3.36) better VQN than GK Öthalom (47.71), but in 2019, GK Öthalom (64.5) gave considerably ($LSD_{5\%}$: 3.49) higher VQN, compared to Mv Ispán (46.69). Increasing fertilizer doses (C: 1.38 min; $N_{90}P_{68}K_{80}$: 2.02 min; $N_{150}P_{113}K_{133}$: 2.42 min) significantly improved DDT, also 2019 (2.13 min) gave observably (+22.4%) greater DDT values compared to 2018 (1.74 min). GK Öthalom (2.19 min) had noticeably higher DDT than Mv Ispán (1.68 min). In 2018, sweet corn (1.92 min) gave significantly ($LSD_{5\%}$: 0.32 min) higher DDT than sunflower (1.56 min). Our results corroborated the statements of Tanács & Gerő (2003) and Linina et al. (2014). Valorigraphic dough stability was significantly increased by both fertilizer dosage (C: 3.52 min; $N_{90}P_{68}K_{80}$: 7.4 min; $N_{150}P_{113}K_{133}$: 8.7 min), also 2019 (7.25 min) gave appreciably (+24.6%) greater values than 2018 (5.82 min). The difference between years also reappeared in the research of Koppel & Ingver (2010). Moreover, GK Öthalom (7.53 min) had significantly higher ST values, compared to Mv Ispán (5.55 min), however forecrops did not affect results in general. In 2018, in the case of control samples, sweet corn (2.88 min) gave significantly ($LSD_{5\%}$: 0.65 min) higher ST, than sunflower (2.06 min). In 2019, scrutinizing the $N_{90}P_{68}K_{80}$ treatment samples, GK Öthalom (10.56 min) had observably ($LSD_{5\%}$: 1.55 min), two times greater ST, compared to Mv Ispán (5.15 min). Dough softening was significantly improved by both fertilizer doses (C: 155.21 VU; $N_{90}P_{68}K_{80}$: 122.03 VU; $N_{150}P_{113}K_{133}$: 108.28 VU). In addition to this, GK Öthalom (122.22 VU) had significantly lower DS values than Mv Ispán (134.79 VU), also 2019 (118.89 VU) gave observably (-14%) less DS than 2018 (138.13 VU). In 2018, sweet corn (146.67 VU) gave significantly ($LSD_{5\%}$: 15.39) better DS, compared to sunflower (129.58 VU). In 2019, GK Öthalom (99.44 VU) had better ($LSD_{5\%}$: 13.9) DS, compared to Mv Ispán (138.33 VU). These findings were in compliance with Wooding et al. (2000) and Tanács & Gerő (2003).

Studying the promilographic water absorption, it can be concluded that, Mv Ispán (51.84%) had significantly higher PWA, than GK Öthalom (49.17%), but there was no difference between years and forecrops, however fertilizing ($N_{90}P_{68}K_{80}$:50.73%; $N_{150}P_{113}K_{133}$: 51.02%) increased PWA compared to control samples (49.77%). In 2018, Mv Ispán (53.66%) had significantly ($LSD_{5\%}$: 1.03%) better PWA, than GK Öthalom (49.43%) with $N_{150}P_{113}K_{133}$: treatment, but this difference was smaller ($LSD_{5\%}$: 0.28%) in 2019, where Mv Ispán owned 51.34%, till then GK Öthalom 49.63% PWA. Fertilizing did not affect promilographic ductility resistance, but 2019 (481.7) gave significantly higher (+37.6%) PDR, than 2018 (349.96). Also, Mv Ispán (441.47) owned observably greater PDR, compared to GK Öthalom (390.19), and sunflower (445.8) improved significantly values than sweet corn (385.86). In 2019, the difference was even higher between forecrops, where sunflower (542.51) gave significantly (32.57) greater PDR, than sweet corn (420.89). Both fertilizer dosage (C: 98.92; $N_{90}P_{68}K_{80}$: 114.45; $N_{150}P_{113}K_{133}$: 122.83) increased significantly the promilographic ductility, just like in the research of Wooding et al. (2000), but forecrops caused no change. GK Öthalom

(115.23) owned significantly greater PD values, than Mv Ispán (108.9). Besides this, 2019 (115.44) gave appreciably (*LSD*$_{5\%}$: 5.49) better (+6%) PD, compared to 2018 (108.69). $N_{150}P_{113}K_{133}$ dosage (547.85) significantly (*LSD*$_{5\%}$: 71.9) augmented promilographic maximum resistance compared with control samples (450.84). 2019 (608.17) gave significantly (*LSD*$_{5\%}$: 43.89) greater (+51.5%) PMR values than 2018 (401.46), however forecrops and cultivars did not differ perceptibly in general. In 2018, Mv Ispán (455.71) had significantly (*LSD*$_{5\%}$: 56.82) higher PMR, than GK Öthalom (347.21), this difference was even higher in the case of control treatment, where Mv Ispán had 431.75, till then GK Öthalom had 254.38 PMR. In 2019, sunflower (677.06) gave significantly (*LSD*$_{5\%}$: 46.4) greater PMR, than sweet corn (539.29). In contrast with 2018, in 2019 GK Öthalom (672.5) gave considerably (*LSD*$_{5\%}$: 73.14) higher PMR, than Mv Ispán (566.5) with $N_{90}P_{68}K_{80}$ dosage. In general, both fertilizer dosages ($N_{90}P_{68}K_{80}$: 75.44; $N_{150}P_{113}K_{133}$: 85.7) increased significantly promilographic energy, compared to control samples (58.9). 2019 (88.65) gave appreciably higher (+52.7%) PE than 2018 (58.04), nevertheless cultivars and forecrops made no difference. In 2018, there was observable difference between the studied varieties, namely Mv Ispán (63.96) had significantly (*LSD*$_{5\%}$: 9.35) higher PE, than GK Öthalom (52.13), but in 2019 GK Öthalom (96.0) possessed higher (*LSD*$_{5\%}$: 10.34) values, than Mv Ispán (81.29). Also, sunflower (96.81) gave observably (*LSD*$_{5\%}$: 10.12) greater PE, than sweet corn (80.49).

Sunflower (93.66) gave significantly greater alveographic P, than sweet corn (82.64), also Mv Ispán (101.61) owned higher P compared to GK Öthalom (74.69), but year and fertilizing made no difference in general. This phenomenon was in contrast with Matuz et al. (2007), who stated that fertilizing significantly increased P. Studying alveographic L, it can be concluded, that both fertilizer doses (C: 52.36; $N_{90}P_{68}K_{80}$: 80.79; $N_{150}P_{113}K_{133}$: 92.81) increased significantly the values, also GK Öthalom (84.74) owned observably higher L, than Mv Ispán (65.9). Year and preceding crop made no difference in general. In the case of control samples, in 2018 sweet corn (51.9) gave significantly (*LSD*$_{5\%}$: 7.98) greater L compared to sunflower (35.5). Generally, there was no difference between the P/L values of the studied years, however Mv Ispán (1.71) had significantly higher P/L than GK Öthalom (0.98). In addition, sunflower (1.53) gave significantly greater P/L, than sweet corn (1.16). $N_{150}P_{113}K_{133}$ treatment (1.87) increased appreciably (*LSD*$_{5\%}$: 0.27) P/L, compared to control (0.99) and $N_{90}P_{68}K_{80}$ dose (1.16). Both fertilizer dosages (C: 165.51; $N_{90}P_{68}K_{80}$: 243.13; $N_{150}P_{113}K_{133}$: 275.65) increased significantly the alveographic W, also 2019 (254.18) gave greater (+25.8%) W, than 2018 (202.02), but forecrop and cultivar did not affect W. In 2018, Mv Ispán (228.63) possessed significantly (*LSD*$_{5\%}$: 35.11) greater W than GK Öthalom (175.4). In 2019, sunflower (217.03) gave significantly (*LSD*$_{5\%}$: 30.62) higher W compared to sweet corn (181.52). The effect of fertilizing on P/L and W were in agreement with Garrido-Lestache et al. (2004).

Comparing to control samples (822.55 cm^3), fertilizing ($N_{90}P_{68}K_{80}$: 883.7 cm^3; $N_{150}P_{113}K_{133}$: 897.87 cm^3) augmented significantly loaf volume, also GK Öthalom (896.11 cm^3) had appreciably greater LV, than Mv Ispán (839.97 cm^3). Loaf volume (Fig. 4) results were significantly higher (+16.3%) in 2019 (933.47 cm^3), compared to 2018 (802.6 cm^3), but there was no difference between studied preceding crops in general. However, in 2018 sweet corn (823.54 cm^3) gave significantly (*LSD*$_{5\%}$: 32.49 cm^3) better LV, than sunflower (781.67 cm^3). In 2019, GK Öthalom (983.13 cm3) gave significantly (*LSD*$_{5\%}$: 42.48 cm^3) better LV, than Mv Ispán (904.17 cm^3) with

$N_{90}P_{68}K_{80}$ treatment. The effect of fertilizer and year were in compliance with Koppel & Ingver (2003) and Massoudifar et al. (2014). 2018 (2.07) gave significantly higher loaf form ratio, than 2019 (1.93). Studying cultivars, Mv Ispán (2.07) owned greater, than GK Öthalom (1.92). Both fertilizer dosages (C: 1.84; $N_{90}P_{68}K_{80}$: 2.0; $N_{150}P_{113}K_{133}$: 2.15) increased significantly LFR, just like in the experiment of Pollhamer (1965). In 2019, in the case of control samples, sunflower (1.85) gave significantly ($LSD_{5\%}$: 0.08) higher LFR, than sweet corn (1.76).

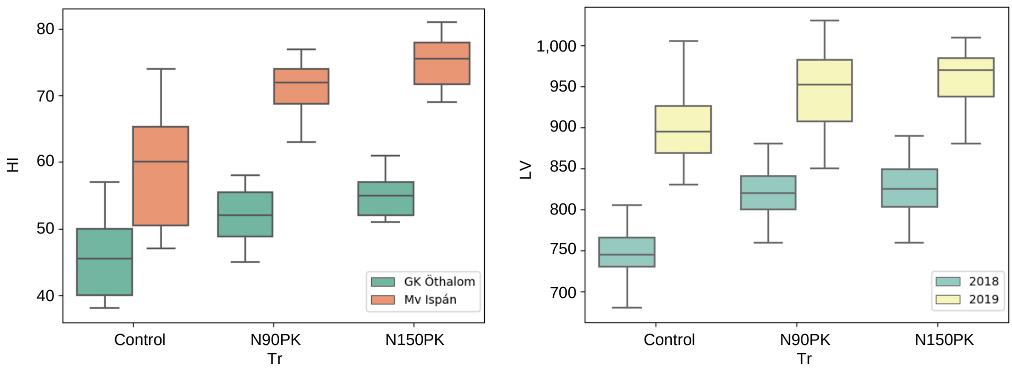

Figure 4. Effect of cultivars, year, treatment on Hardness index (left) and loaf volume (right).

Scrutinizing starch damage (UCD), only cultivars differed significantly, namely Mv Ispán (22.58) had greater values than GK Öthalom (18.52), which results affirmed the findings of Lukow & McVetty (1991).

Fertilizing ($N_{90}P_{68}K_{80}$: 82.59; $N_{150}P_{113}K_{133}$: 83.45) significantly increased average particle size compared to control treatments (76.02), but years did not differ in general. A similar conclusion was done by Cho et al. (2018). Mv Ispán (82.59) possessed observably greater PSD, than GK Öthalom (78.78). Sweet corn (81.7) gave significantly higher PSD than sunflower (79.67).

2018 (41.74) gave significantly higher kernel weight, than 2019 (40.68), which confirmed the findings of Muchová (2003) and Guarda et al. (2004). In addition, GK Öthalom (42.16) owned significantly greater KW, compared to Mv Ispán (40.26). Fertilizing ($N_{90}P_{68}K_{80}$: 41.42; $N_{150}P_{113}K_{133}$: 42.12) increased observably KW in contrast with control samples (40.1). In 2018, in the case of control treatment, sweet corn (41.91) gave significantly ($LSD_{5\%}$: 2.24) greater KW, than sunflower (37.48).

Generally fertilizing and preceding crop had no effect on kernel diameter, however 2018 (3.02) gave significantly greater KD, than 2019 (2.97), also GK Öthalom (3.05) possessed appreciably higher KD in contrast with Mv Ispán (2.95).

Except forecrop, all the other 3 factors had statistically provable effect on Hardness Index. Mv Ispán (68.3) owned significantly higher HI (Fig. 4), than GK Öthalom (50.96). Also, 2019 (63.34) gave greater (+13.3%) HI compared to 2018 (55.92). Fertilizing ($N_{90}P_{68}K_{80}$: 61.54; $N_{150}P_{113}K_{133}$: 65.04) increased significantly HI in contrast with control treatment (52.3), as well as in the research of Guarda et al. (2004).

Table 6. Effect of the studied factors on the remaining parameters (Debrecen, Hungary)

Yr	Cv	Fc	Tr	FE (%)	GI (%)	LFR	LV (cm^3)	SD	Mavg (μm)	KW (mg)	KD (mm)	HI (%)
2018	GK Öthalom	Sweet corn	Ø	73.1	98.7	1.86	791	19.23	75.05	41.55	3.07	41
			$N_{90}P_{68}K_{80}$	74.5	87.0	1.87	873	18.23	83.05	43.50	3.08	51
			$N_{150}P_{113}K_{133}$	73.2	81.2	1.96	900	17.90	84.07	42.65	3.06	53
		Sunflower	Ø	71.0	98.3	1.85	743	18.45	67.09	35.38	2.94	40
			$N_{90}P_{68}K_{80}$	73.7	71.2	2.06	795	17.80	81.13	44.68	3.14	49
			$N_{150}P_{113}K_{133}$	73.5	62.9	2.14	838	17.98	82.87	44.90	3.13	53
	Mv Ispán	Sweet corn	Ø	73.4	83.5	1.85	756	22.08	79.71	42.28	3.00	57
			$N_{90}P_{68}K_{80}$	71.8	69.4	2.26	820	22.30	86.55	41.30	2.96	69
			$N_{150}P_{113}K_{133}$	71.0	66.3	2.51	801	22.55	86.89	40.58	2.92	71
		Sunflower	Ø	71.0	92.2	1.95	705	21.40	74.74	39.58	3.03	48
			$N_{90}P_{68}K_{80}$	71.1	63.7	2.16	808	22.48	85.42	42.03	2.99	68
			$N_{150}P_{113}K_{133}$	70.3	71.8	2.31	803	23.35	88.31	42.45	2.99	73
2019	GK Öthalom	Sweet corn	Ø	68.5	98.5	1.75	932	19.23	78.10	41.33	3.01	50
			$N_{90}P_{68}K_{80}$	68.7	94.8	1.90	969	18.53	81.08	43.08	3.04	57
			$N_{150}P_{113}K_{133}$	69.4	94.4	1.92	983	18.95	81.93	42.00	3.00	58
		Sunflower	Ø	68.9	98.6	1.86	938	19.43	74.25	40.65	2.98	53
			$N_{90}P_{68}K_{80}$	68.5	97.2	1.87	998	18.55	78.65	42.98	3.09	53
			$N_{150}P_{113}K_{133}$	68.8	97.5	2.04	997	18.03	78.10	43.20	3.06	56
	Mv Ispán	Sweet corn	Ø	67.8	97.1	1.76	886	23.35	78.98	38.60	2.93	65
			$N_{90}P_{68}K_{80}$	66.9	90.0	1.95	935	23.05	81.93	40.00	2.93	75
			$N_{150}P_{113}K_{133}$	65.5	82.6	2.10	955	22.55	83.10	38.05	2.86	79
		Sunflower	Ø	67.8	97.0	1.85	830	22.63	80.28	41.40	2.99	65
			$N_{90}P_{68}K_{80}$	66.6	94.1	1.95	873	22.80	82.90	39.37	2.90	72
			$N_{150}P_{113}K_{133}$	66.6	85.1	2.21	908	22.45	82.33	37.55	2.84	77
			$LSD_{5\%}$ (Yr):	0.64	4.37	0.08	23.86	0.88	1.94	1.03	0.03	4.46
			$LSD_{5\%}$ (Cv):	1.06	5.14	0.08	33.99	0.31	1.79	0.98	0.03	3.10
			$LSD_{5\%}$ (Fc):	1.12	5.35	0.09	35.33	0.89	1.91	1.06	0.04	4.70
			$LSD_{5\%}$ (Tr):	1.37	5.70	0.09	40.95	1.09	1.79	1.26	0.04	5.12

Pearson's correlation analysis:

The results of the Pearson correlation analysis can be seen in Table 7, where only those values are shown, which was at least ± 0.5. Fertilizing was in tight correlation with CP (0.812**), ZI (0.776**) and WGC (0.828**); in medium with VQN (0.704**), DDT (0.571**), ST (0.711**), PD (0.721**), W (0.726**), L (0.746**), LFR (0.588**) and Mavg (0.675**); however fertilizing was in negative medium correlation with DS (-0.634**) and P/L (-0.573**). Similar results were got by Masauskiene & Ceseviciene (2005) and Eser et al. (2017). These results suggest that, proper nutrient supply is essential for growing wheat with good rheologic and protein properties.

Table 7. Pearson's correlation analysis

/	F	CP	ZI	WGC	GI	GS	FE	VWA	VQN	DDT	ST	DS	PWA	PDR	PD	PMR	PE	P	L	P/L	W	LFR	LV	SD	Mavg	KD	HI
F	1																										
CP	0.812**	1																									
ZI	0.776**	0.958**	1																								
WGC	0.828**	0.941**	0.898**	1																							
GI	-.504**				1																						
GS					-.721**	1																					
FE							1																				
VWA								1																			
VQN	0.704**	0.866**	0.869**	0.808**					1																		
DDT	0.571**	0.739**	0.755**	0.668**					0.874**	1																	
ST	0.711**	0.856**	0.842**	0.812**					0.968**	0.884**	1																
DS	-.634**	-.796**	-.818**	-.732**					-.967**	-.790**	-.910**	1															
PWA								0.924**					1														
PDR							-.550**							1													
PD	0.721**	0.794**	0.750**	0.767**					0.744**	0.694**	0.768**	-.642**			1												
PMR			0.538**				-.581**		0.554**		0.507**	-.626**		0.926**		1											
PE		0.628**	0.694**	0.588**			-.526**		0.719**	0.633**	0.688**	-.745**		0.763**	0.608**	0.934**	1										
P								.712**					0.652**	0.540**				1									
L	0.746**	0.906**	0.831**	0.843**					0.799**	0.727**	0.810**	-.732**			0.781**		0.510**		1								
P/L	-.573**	-.746**	-.632**	-.674**					-.643**	-.589**	-.651**	0.561**			-.701**			0.632**	-.867**	1							
W	0.726**	0.831**	0.871**	0.818**					0.842**	0.694**	0.805**	-.821**			0.743**	0.680**	0.806**		0.689**		1						
LFR	0.588**				-.678**			0.569**					0.597**									1					
LV		0.579**	0.539**						0.622**	0.596**	0.603**	-.590**			0.594**	0.595**	0.693**		0.542**	-.520**	0.608**		1				
SD								0.818**					0.792**					0.724**						1			
Mavg	0.675**	0.694**	0.711**	0.690**	-.629**			0.703**	0.511**				0.679**								0.618**	0.567**			1		
KD							0.570**																	-.620**		1	
HI							-.524**	0.854**					0.790**					0.591**			0.631**			0.774**	0.658**	-.627**	1

The importance of good crude protein content has to be emphasized, because 26/15 (58%) of the studied parameters in PCC were at least in medium correlation with CP, namely positive, very tight with WGC (0.941**), ZI (0.958**) and L (0.906**); tight with VWA (0.866**), ST (0.856**), PD (0.794**) and W (0.831**); in medium with DDT (0.739**), PE (0.628**), LV (0.579**) and Mavg (0.694**); but in negative, tight with DS (-0.796**) and negative, medium with P/L (-0.650**). Practically, the higher the CP is, the more the WGC is, and it develops slower, but it stays more stable after kneading, and the dough made out of it will be more ductile, which attributes are essential for getting loaves with good volume.

The other decisive attribute was wet gluten content, since 26/14 (54%) of the studied properties were at least in medium correlation with WGC. This parameter was in very tight relationship with CP (0.941**), ZI (0.898**), VQN (0.808**), ST (0.812**), PD (0.767**), W (0.818**) and L (0.843**); in medium, positive with DDT (0.668**), PE (0.588**) and Mavg (0.690**); meanwhile in negative, medium with DS (-0.732**) and P/L (-0.674**).

Studying gluten quality, Zeleny index was in very tight, positive correlation with CP (0.958**); in tight with WGC (0.898**), VQN (0.869**), DDT (0.755**), ST (0.842**), PD (0.750**), W (0.871**) and L (0.831**); in medium with PMR (0.538**), Mavg (0.711**), PE (0.694**) and LV (0.539**); but in negative, tight with P/L (-0.632**) and DS (-0.818**). The relationship of GS (-0.721**), LV (-0.678**) and Mavg (-0.629**) with gluten index was negative, medium.

Valorigraphic water absorption was in very tight correlation with PWA (0.924**); in tight with starch damage (0.818**) and Hardness index (0.854**); in medium with Mavg (0.703**), LV (0.569**) and P (0.712**). These results suggest that, the harder the grain is, higher the starch damage and average particle size are, which results in better water absorption because of the increased surface. VQN was in very tight relationship with ST (0.968**), in tight with ZI (0.869**), CP (0.866**), DDT (0.874**), W (0.842**), L (0.799**) and WGC (0.808**); in medium with PD (0.744**), PMR (0.554**), PE (0.719**), LV (0.622**) and Mavg (0.511**) so it can be concluded that, the VQN can predict well some rheological parameters. DDT and ST showed almost the same correlations like VQN. Dough softening was in negative, very tight relationship with VQN (-0.967**) and ST (-0.910**); in tight with CP (-0.796**), ZI (-0.818**), DDT (-0.790**) and W (-0.821**); in medium with WGC (-0.732**), PD (-0.642**), PMR (-0.626**), PE (-0.745**), L (-0.732**) and LV (-0.590**); however in positive, medium with P/L (0.561**).

Promilographic water absorption was in very tight relationship with VWA (0.924**); in tight with HI (0.790**) and SD (0.792**); in medium with P (0.652**), LV (0.597**) and Mavg (0.679**). PDR was in very tight correlation with PMR (0.926**); in tight with PE (0.763**); in medium with P (0.540**); meanwhile in negative, medium with FE (-0.550**). Promilographic ductility was tight relationship with CP (0.794**), ZI (0.750**), WGC (0.767**), ST (0.768**) and L (0.781**); in medium with VQN (0.744**), DDT (0.694**), PE (0.608**), LV (0.594**) and W (0.743**); but in negative, medium with DS (-0.642**) and P/L (-0.701**). PMR was in very tight, positive correlation with PDR (0.926**) and PE (0.934**); in medium with VQN (0.554**), ST (0.507**), W (0.680**) and LV (0.595**); in negative, medium with FE (-0.581**) and DS (-0.626**). Studying promilographic energy, it can be summed that, PE was in medium, positive relationship with CP (0.628**),

ZI (0.694**), WGC (0.588**), VQN (0.719**), DDT (0.633**), ST (0.688**), PD (0.608**), L (0.510**) and LV (0.693**), in tight with PDR (0.763**) and W (0.806**); in very tight with PMR (0.763**); but in negative, medium with FE (-0.522**) and DS (-0.745**). Comparing alveographic and promilographic results, it can be seen that, W and PE; L and PD correlated significantly.

Alveographic P was in medium, positive correlation with VWA (0.712**), PWA (0.652**), PDR (0.540**), HI (0.591**), P/L (0.632**) and SD (0.724**). The correlation of P with VWA and SD was also observed by Preston et al. (1987). L was in medium, negative correlation with DS (-0.732**); but in very tight, positive with CP (0.906**); in tight with ZI (0.831**), WGC (0.843**), VQN (0.799**), ST (0.810**) and PD (0.781**); in medium with DDT (0.727**), PE (0.510**), W (0.689**) and LV (0.542**). Our results affirmed the findings of Sipos et al. (2007), where they found tight correlation between L, VQN, WGC, CP and extensibility. P/L was in medium, negative relationship with CP (-0.746**), WGC (-0.674**), ZI (-0.632**), GS (-0.506**), VQN (-0.643**), DDT (-0.589**), ST (-0.651**), PD (-0.701**) and LV (-0.520**); in tight with L (-0.867**); meanwhile in positive, medium with DS (0.561**) and P (0.632**). One of the most important parameter of alveograph is W, which was in tight, positive correlation with CP (0.831**), ZI (0.871**), WGC (0.818**), VQN (0.842**), ST (0.805**), PE (0.806**); in medium with DDT (0.694**), PD (0.743**), PMR (0.680**), L (0.689**), LV (0.608**), Mavg (0.618**) and HI (0.631**); but in negative, tight with DS (-0.821**). The correlation of CP and WGC with W have been previously reported also by Sipos et al. (2007).

Considering parameters of baking test, LFR was in medium, positive relationship with Mavg (0.567**), VWA (0.569**) and PWA (0.597**); but in negative, medium with GI (-0.678**). In addition, loaf volume was in medium, positive correlation with CP (0.579**), ZI (0.539**), VQN (0.622**), DDT (0.596**), ST (0.603**), PD (0.594**), L (0.542**), PMR (0.595**), PE (0.693**) and W (0.608**); but in negative, medium with DS (-0.590**) and P/L (-0.520**). These findings are connecting to the statement of Gabriel et al. (2017), because the correlation between LV and CP was only medium positive, meanwhile W and PE, the main parameters of alveograph and promylograph were in tighter relationship with LV. Cho et al. (2018) reported similar alterations in the case of CP, DDT and ST with LV. These values suggest that, good volume loaf can only be baked from flours with proper protein and ductility parameters.

Starch damage was in tight, positive relationship with VWA (0.818**), PWA (0.792**) and HI (0.774**); in medium with P (0.724**); but in negative, medium with KD (-0.620**). Mavg was in medium, positive relationship with CP (0.694**), ZI (0.711**), WGC (0.690**), VWA (0.703**), PWA (0.679**), VQN (0.511**), W (0.618**), LV (0.567**) and HI (0.658**); but in negative, medium with GI (-0.629**). The relationship of water absorption and PSD is in compliance with the findings of Preston & Williams (2003). Kernel diameter was in medium, positive correlation with flour extraction (0.570**), meanwhile in negative, medium with HI (-0.627**).

Studying the relationship of Hardness index with other attributes: HI was in tight, positive correlation with SD (0.774**), VWA (0.854**) and PWA (0.790**); in medium with P (0.591**), W (0.631**) and Mavg (0.658**); but in negative, medium with FE (-0.524**) and KD (-0.627**). These results affirmed the findings of Eliasson and

Larsson (1993) and Manley (1995), namely the kernel hardness can determine starch damage, water absorption, PSD and flour extraction as well.

CONCLUSIONS

The outstanding yields of the 1st growing season can be explained by the fair water supply (+149.5 mm compared to 30-year avg.), in addition, lack of precipitation and the detrimental effect of the rapid warming in February (+2.5 °C compared to 30-year avg.) and March (+3 °C compared to 30-year avg.) considering the 2nd growing season. Nevertheless, the quality parameters of the studied samples were appreciably better in the 2nd growing season, due to the ecological parameters of 2019 (mild weather of April and May and average annual precipitation). This phenomena was also discussed by Pepó (2010a), Tayyar (2010), Pepó & Sárvári (2011), Gooding et al. (2017) and Szabó et al. (2017). The ecological conditions of the 2nd growing season also significantly affected the quality parameters of the classic winter wheat cultivar, GK Öthalom, which are reflected mainly in the improvement of all protein linked attributes (CP, WGC, ZI, GS, VQN, ST, DS, PMR, PE and LV).

Addition of fertilizer significantly augmented the quality parameters, however in the case of some properties (Y, VWA, PWA, PMR, PE, LV, Mavg, KW, HI) increasing the amount of fertilizer above $N_{90}P_{68}K_{80}$ dosage, had no further, statistically provable improver effect. Thinking over these results, like yield, water absorption and loaf volume, which are one of the most determinative parameters for the baking industry, it can be summed that, $N_{90}P_{68}K_{80}$ dosage was enough to realize the quality and yield potential of the studied genotypes. Moreover, the measured data indicates that fertilizing plays a decisive role in determining the main post-harvest quality indicators considering the Hungarian wheat standard, like crude protein, wet gluten content, Zeleny index, VQN, stability, W and P/L, because even the $N_{150}P_{113}K_{133}$ dosage significantly increased them, which is substantial since more than half of the Hungarian wheat production is exported.

The results in the 1st growing season suggest that, in the case of suboptimal nutrient supply, choosing of the right preceding crop can considerably improve the yield and quality parameters (Y, CP, DGC, ZI, FE, VQN, DDT, ST, DS, PDR, PMR, PE, Mavg and all alveographic values) of winter wheat, which has been already partly reported by Pepó (2010c). In our case, sweet corn performed better because the deep root system of sunflower exploits the nutrient and water supply of the soil.

In the perspective of the baking industry, one of the most eloquent quality indicators is the baking test, more precisely loaf volume, which was in medium, positive correlation with the main parameters of all the used methods: VQN (0.622**), PE (0.693**) and W (0.608**) in the Pearson's correlation analysis. Also, the importance of Hardness Index has to be underlined, because it was in a tight relationship with starch damage (0.774**) and water absorption (0.854**); medium with Mavg (0.658**) and W (0.631**).

Effect of studied agrotechnical factors on gluten quality can be observed in the change of gluten index and gluten spread. GI was considerably affected by year, cultivar and fertilization, meanwhile GS was influenced observably by year, preceding crop and fertilization. To compile, increment of fertilizer, high temperature in April and May, large amount of annual precipitation and sunflower (exploitive) as preceding crop deteriorate the gluten strength.

Variety-specific agronomy practice has to be pointed out, due to there were significant differences between the studied varieties in general, considering GI, FE, VWA, DDT, ST, DS, PDR, PD, P, L, P/L, LV, LFR, SD, Mavg, KW, KD and HI values. Only one sample, GK Öthalom (2019, sweet corn and $N_{90}P_{68}K_{80}$) met the requirements of the Hungarian I. class except one parameter, the Zeleny index, all the other studied samples met maximum the requirements of II. class, which shows well that none of the examined growing seasons was optimal for the generative development of winter wheat. Besides this, without fertilizing, none of the samples met the minimal specifications of II. class, which means that they could be only sold for feed purposes. It has been previously reported that fertilizing exerts a strong influence on the baking quality of wheat (Borghi et al., 1995).

Summarizing, these data contribute to a better understanding of the effect of agrotechnical factors on the quality and yielding of winter wheat, and the relationships between the parameters of the common and infrequently-used methods.

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