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Wheat rheological and Mixolab quality in relation to cropping systems and plant nutrition sources

Magdaléna Lacko-Bartošová[1], Lucia Lacko-Bartošová[1], Petr Konvalina[2]*

[1]*Department of Sustainable Agriculture and Herbology, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Nitra, Slovakia*

[2]*Department of Agroecosystems, Faculty of Agriculture, University of South Bohemia in České Budějovice, České Budějovice, Czech Republic*

**Corresponding author: lucialbartosova@gmail.com*

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Abstract: The objective of this study was to evaluate the effect of cropping systems [integrated (INT) *vs.* organic (ORG)] and plant nutrition sources (synthetic in INT *vs.* approved organic in ORG) on analytical and rheological quality traits of winter wheat and its productivity. The results after 16 years of field experiments were evaluated. Pre-crop for winter wheat was N-fixing crop. Grain yield of winter wheat (6.8 t ha^{-1} in INT, 6.5 t ha^{-1} in ORG) did not differ significantly, while plant nutrition sources had an equal and positive effect on the yield. Crude protein quantity was higher in INT system by about 0.2%. The farinograph dough development time and dough stability were the longest for ORG and fertilised treatments. Mixolab quality indicators showed a clear distinction between ORG and INT systems and fertilisation in the protein and starch characteristics of the grain. The ORG reported longer Mixolab stability of the dough, mainly on fertilised treatment (8.8 min). Starch characteristics – torque C4 (amylolytic activity) and torque C5 (starch retrogradation) were higher for ORG system. Torque C2, protein weakening, was not affected by the cropping system. ORG system has the potential to achieve consistent, high-quality yields with significantly lower reliance on external inputs.

Keywords: winter wheat; rheology; Mixolab quality; yield; organic system

Agriculture is faced with a context of increasing policy requirements to use synthetic inputs efficiently and growing demands of consumers for organic produce with potential health and environmental benefits (Lacko-Bartošová and Neugschwandtner 2012). In the future, reduction of nitrogen (N) fertilisers is foreseen, with expectations of beneficial environmental impacts, reduction of energy requirements and costs for farmers (Zörb et al. 2018).

The most important plant nutrient is nitrogen, with a notable effect not only on yield formation but also on the baking quality of wheat (Xue et al. 2016). In an organic system, agronomic strategies and N sources should be adapted, and nutrient management optimised without grain quality and quantity losses (Zörb et al. 2018). In an organic system, the management of N nutrition used to be based on: *i*) increasing the presence of legumes in the crop rotation (Thomsen et al. 2013), *ii*) broadcasting organic compounds before sowing (Mazzoncini et al. 2015), or *iii*) adopting cereal-legume intercropping (Pelzer et al. 2012).

Protein content and quality have a major influence on the baking potential of wheat flour. Literature evidence on the effect of the cropping system on the yield

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and quality of crops are often contradictory. Wheat quality depends on the genetic factors, environmental conditions, growth locations, and agronomic practices prevailing during different wheat growth stages (Mäder et al. 2007; Váňová et al. 2008). Research results showed an inverse correlation between yield and protein content, with a strong effect of N fertilisation (Shewry et al. 2013). L-Baeckström et al. (2004) observed a clear difference in baking quality between organic and non-organic wheat, with higher baking quality of non-organic one. Pandino et al. (2020) confirmed the key role of the cropping system on the grain yield and protein quantity of durum wheat, with a dependency of quality traits on genotype. Under European site conditions, the crude protein (CP) content of organic wheat was 77% to 94% of conventional ones (Mäder et al. 2007; Hildermann et al. 2009).

There is little experimental evidence on the effect of certified organic plant nutrition products on the technological, nutritional, and baking quality of winter wheat (Jablonskytė-Raščė et al. 2013).

The aim of this study was to investigate the technological quality characteristics and productivity of winter wheat as influenced by different cropping system and the use of plant nutrition sources (organic *vs.* synthetic) during two growing years within a long-term field trial. For this purpose, flour farinograph rheological quality indicators, Mixolab characteristics, and analytical grain quality parameters were evaluated.

MATERIAL AND METHODS

Experimental site and field trial. A long-term cropping systems experiment has been conducted at the Field experimental station of the Faculty of Agrobiology and Food Resources, Slovak University of Agriculture (SUA) in Nitra since 1999. The soil type is a haplic luvisol developed at proluvial sediments mixed with loess. The elevation of experimental fields is 178 m a.s.l., the climate is continental. The average long-term (1961–2000) annual rainfall is 547.6 mm, the average long-term temperature is 9.9 °C.

The experimental factors were cropping systems, fertilisation, and growing years (2014/2015 and 2015/2016). The share of crops in the two cropping systems, organic (ORG) and integrated (INT), is summarised in Table 1. Pre-crop for winter wheat was lucerne. The fertilisation treatments were fertilised (F) and non-fertilised (NF) (without manure and fertilisers) variants. A split-plot design was used with cropping systems as the main factor; subplots were fertilisation variants. Complete crop rotations were performed every year in four replicates, the area of one plot was 100 m^2. In both cropping systems, the fertilised treatments were based on 40 t ha^{-1} of manure which was applied for maize (4 years before wheat sowing) with medium depth ploughing. In both systems, additional fertilisers were used. For winter wheat, the application rate was calculated based on the macronutrient content in soil and plant needs to obtain the yield of 6 t ha^{-1}. The data are summarised in Table 2.

Table 1. Share of crops in two cropping systems (%)

Crop	Organic	Integrated
Cereals (wheat, barley)	33.3	50.0
Perennial legumes (lucerne)	33.3	16.7
Annual legumes (peas)	16.7	16.7
Row crops (maize)	16.7	16.7

Synthetic fertilisers in INT system were applied in three (in 2014/2015: before sowing; regeneration dose at BBCH 12; productive dose at BBCH 28) and two (in 2016 only spring) split applications. In ORG system, organic fertiliser approved for organic agriculture (Flovenal, Slovakia) was used in March (BBCH 22–28). Weeds were managed mechanically in ORG system, in INT system by herbicides. It was not necessary to use fungicides and insecticides. Soil tillage was based on ploughing at a depth of 0.2 m in both systems.

Meteorological conditions during two growing years are shown in Figure 1.

Plant material and data collection. Plots of winter wheat variety Laudis were combine harvested at maturity (14% moisture content), thousand grain weight (TGW in g) was determined from the harvested grains, 2 × 500 grains. Winter wheat yield and TGW were measured in four replicates.

Quality traits. Indirect indicators of baking quality were analysed on the whole grain meal in four replicates.

Wheat samples were milled using PSY MP20 (Mezos, Czech Republic); falling number (FN) was determined on FN 1100 (Perten Inst., Sweden) according to AACC 56-81 B. CP quantity was calculated from the determination of total nitrogen, using Kjeltec 1002 System (Tecator AB; Hoganas, Sweden) based on N × 5.7 (in dry matter).

Rheological properties of dough were analysed using Brabender farinograph-AT (Brabender Corp., Germany), according to ICC 115/1 method in winter wheat flour obtained by grain milling on Quadrumat Senior (Brabender Corp., Germany). Water absorption capacity (WA) of flour in per cent, dough devel-

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Table 2. Crop management data and doses of nutrient application for winter wheat (kg ha^{-1})

System	Sowing date	Harvest date	Nitrogen	Phosphorus	Potassium
Integrated	10. 10. 2014	14. 07. 2015	60	45	120
	08. 10. 2015	20. 07. 2016	80	40	120
Organic	10. 10. 2014	14. 07. 2015	24	15	36
	08. 10. 2015	20. 07. 2016	60	37	90

opment time (DDT) in minutes, dough stability (DS) in minutes, softening of dough (SD) after 12 min were determined in farinograph units (FU). Mixing tolerance index (MTI) in FU as the difference from the top of the farinograph curve at the peak to the top of the curve measured five min after the peak was determined.

Mixing and pasting behaviours of dough were analysed by Mixolab II (CHOPIN Technologies, France), according to AACCI 54-60.01 method (Dubat 2010).

Measured parameters were:
– Torque C1: initial mixing, targeted objective, torque 1.1 Nm during mixing at 30 °C;
– DS: dough resistance against mixing, calculated as the time in minutes between C1 and decreasing of torque by 11% during constant thermal phase;
– Torque C2: heating, decrease in dough consistency, proteins weakening;
– Torque C3: starch gelatinisation, maximum torque after C2 during heating;
– Torque C4: stability of the hot gel formed, amylolytic activity;
– Torque C5: starch retrogradation during cooling, end of the test;
– Slope α: between C1 and C2 – speed of the protein weakening under heating;
– Slope β: between C2 and C3 – speed of starch gelatinisation;
– Slope γ: between C3 and C4 – enzymatic (α-amylase) degradation speed.

Statistical analysis. Multifactorial analysis of variance (ANOVA), with cropping systems, growing years, and fertilisation treatments as the main factors, was performed. Significant differences between the factors and their interactions were determined by *F*-test at $P < 0.05$; $P < 0.01$; $P < 0.001$ probability levels. Fisher's least significant difference test (LSD) was used to identify significantly different mean values. For statistical analyses the software STATISTICA version 10.0 (Stat-

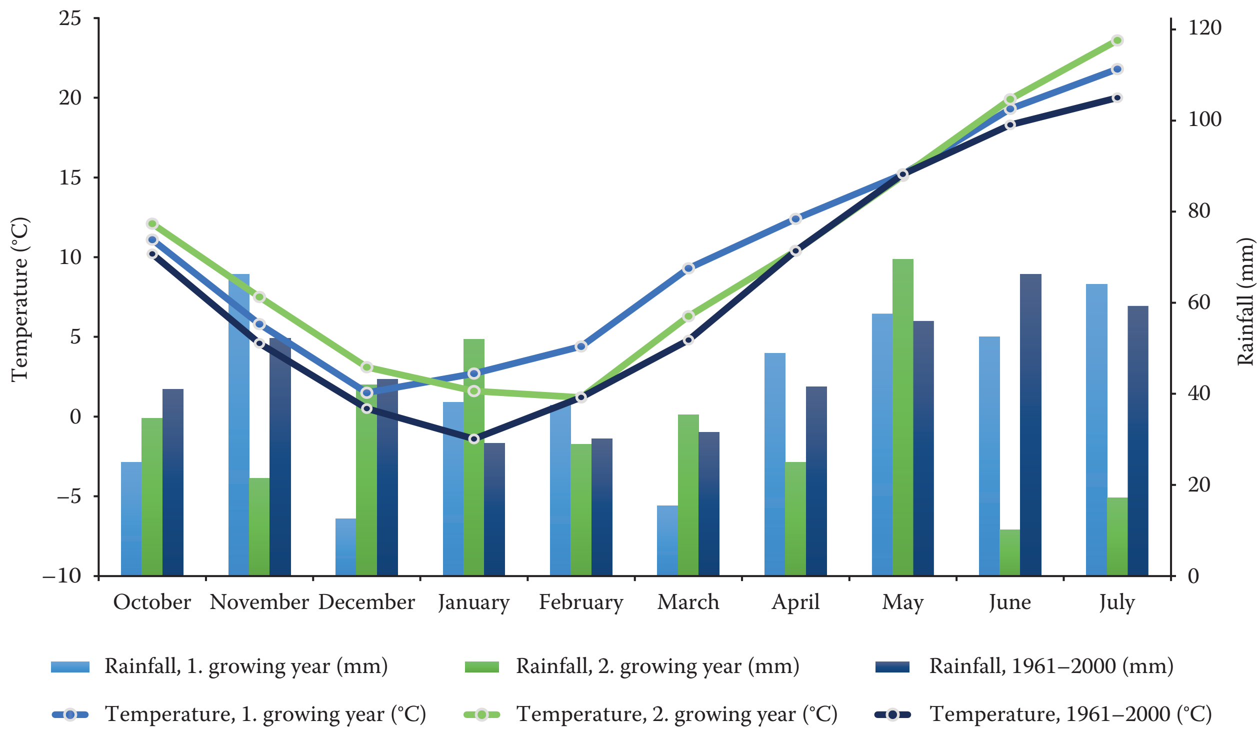

Figure 1. Meteorological conditions during growing years

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Soft, USA) was used. The correlation analysis was applied using Pearson correlation coefficients.

RESULTS AND DISCUSSION

Productivity and indirect indicators of wheat quality. Productivity is usually considered as a bench mark when comparing the performance of cropping systems. Grain yield of winter wheat did not differ significantly after 16 years of cropping systems realisation (Table 3), whereas a significant increase of yield (0.8 t ha^{-1}) was recorded on fertilised treatments. Moreover, differentiated meteorological conditions during two growing years resulted in the highest effect on grain yield (2.5 t ha^{-1}). Interactions of cropping systems × fertilisation were not significant, indicating that different sources of plant nutrition had an equal and positive effect on grain yield. Indirect indicators of wheat quality evaluated in this study were CP quantity, FN, and TGW. The results indicated significant variance among cropping systems, fertilisation (besides FN) and growing years (besides TGW). Quantities of CP and TGW were higher in INT system (11.6%; 45.9 g), FN was high in both systems, indicating low amylolytic activity. Fertilisation treatments, synthetic in INT and organic in ORG, enhanced the quantity of CP by 0.4% and TGW by 2.4 g. Extremely dry and warm weather during maturation of grain in the second growing year resulted in a 1% higher CP quantity. Interactions of cropping systems × fertilisation were not significant for TGW. A positive effect of organic fertiliser itself and in combination with bio-activator on the yield and yield components of common wheat was reported by Jablonskytė-Raščė et al. (2013) but, opposite to our findings, increase in grain yield resulted in the reduction of protein and gluten quantity of wheat.

Farinograph results. Farinograph results indicated a significant effect of cropping systems, fertilisation, growing years and interaction systems × fertilisation for all rheological indicators. Organic wheat flour was characterised by higher WA (61.3%), longer DDT (1.35 min), DS (6.19 min), lower SD (39.0 FU) and lower MTI (45.9 FU) compared to INT, and therefore the flour can be classified as strong. In INT non-fertilised treatments, the shortest DS (2.72 min), highest SD (74.1 FU) and highest MTI (65.9 FU) were determined. Results may be associated with N inputs based only on N-fixing crops in crop rotation. In ORG, NF variant, similar trends were noticed, but a higher share of N-fixing crops compared to INT system resulted in higher DS, lower SD, and MTI.

For commercial organic wheat, Draghici et al. (2011) detected very low DS (0.8 min), lower Zeleny index, gluten, and protein content, which resulted in lower quality of organic flour and bread.

Mixolab analysis. Mixolab analysis has the advantage of being able to measure properties of flour proteins, starch, and associated enzymes in one test. In the first phase, stability as the resistance of dough against mixing was measured; the longer the duration, the stronger the flour. Stability data for wheat usually ranged between 4.4–11.2 min (Koksel et al. 2009; Dubat 2010). The findings presented in Table 4 indicated that ORG winter wheat had about 1.23 min higher stability (6.0 min) compared to INT, and fertilisation improved the deformation resistance of dough by about 4.93 min. Lower stability was achieved at non-fertilised treatments in both systems, with the lowest value in INT system (2.67 min). ORG wheat with organic fertilisation achieved the longest resistance of the dough against mixing (stability 8.83 min). Torque C2, as an indicator of protein weakening, was not affected by the cropping system and reached the average value of 0.5 Nm. Good quality proteins are represented by C2 0.5–0.6 Nm. Lower values than 0.5 Nm were recorded on non-fertilised variants of both systems. Torque C2 was significant for the growing year factor, showing the effect of weather conditions on proteolytic activity. The factors of cropping system and growing year were significant for slope α and the speed of protein weakening, which was lower in INT system (–0.03 Nm min^{-1}).

Starch characteristics measured by Mixolab, such as gelatinisation (C3), amylolytic activity (C4) and starch retrogradation (C5) were significant for all experimental factors (besides C4, fertilisation). Torque C3 was higher for INT system (1.95 Nm) and fertilised treatments, indicating higher starch gelatinisation and higher dough viscosity. Slope β (gelatinisation speed) was significantly lower for INT system and non-fertilised treatments, confirming the slower gelatinisation process. Heat stability of the starch gel at temperature over 80 °C, when consistency decreases as a result of amylolytic activity, phase C4, was significantly lower for INT system (1.72 Nm), fertilisation did not influence this parameter. ORG system was characterised with higher hot starch paste stability (torque C4) and very low α-amylase degradation speed. Torque C5, as the measure of starch retrogradation in the dough during the cooling phase, was significantly higher for ORG winter wheat (3.82 Nm). For the standard sample of wheat flour, Schmiele et al. (2017) reported strong

https://doi.org/10.17221/189/2020-CJFS

Table 3. Quality parameters and productivity of winter wheat (n = 32)

System	CP (%)	FN (s)	WA (%)	DDT (min)	DS (min)	SD (FU)	MTI (FU)	TGW (g)	Yield (t ha^{-1})
Organic	11.4^{b}	451^{a}	61.3^{a}	1.35^{a}	6.19^{a}	39.0^{b}	45.9^{b}	43.0^{b}	6.5
Integrated	11.6^{a}	388^{b}	60.8^{b}	0.96^{b}	4.25^{b}	62.0^{a}	53.9^{a}	45.9^{a}	6.8
Mean ± standard deviation	11.5 ± 0.7	420 ± 109	61.0 ± 0.9	1.15 ± 0.88	5.22 ± 3.48	50.5 ± 21.2	49.9 ± 20.0	44.5 ± 2.6	6.7 ± 1.6
P system	***	**	**	***	***	***	**	***	NS
Fertilisation									
F	11.7^{a}	420	61.5^{a}	1.36^{a}	6.67^{a}	41.8^{b}	39.4^{b}	45.7^{a}	7.1^{a}
NF	11.3^{b}	419	60.6^{b}	0.95^{b}	3.77^{b}	59.2^{a}	60.3^{a}	43.3^{b}	6.3^{b}
P fertilisation	***	NS	**	***	***	***	**	***	**
Year									
2015	11.0^{b}	515^{a}	61.2^{a}	0.74^{b}	6.35^{a}	39.9^{b}	41.3^{b}	44.1	5.4^{b}
2016	12.0^{a}	325^{b}	60.9^{b}	1.57^{a}	4.09^{b}	61.1^{a}	58.4^{a}	44.9	7.9^{a}
P year	***	***	*	***	***	***	**	NS	***
System × fertilisation									
Organic F	11.6^{b}	425^{b}	61.4^{ab}	1.93^{a}	7.56^{a}	33.7^{d}	37.0^{d}	43.9	6.8
Integrated F	11.8^{a}	416^{b}	61.6^{a}	1.13^{b}	5.78^{b}	49.9^{b}	41.9^{c}	47.5	7.4
Organic NF	11.2^{d}	478^{a}	61.2^{b}	0.77^{c}	4.81^{c}	44.3^{c}	54.7^{b}	42.2	6.3
Integrated NF	11.4^{c}	360^{c}	60.1^{c}	0.78^{c}	2.72^{d}	74.1^{a}	65.9^{a}	44.4	6.2
P system × fertilisation	*	**	**	***	*	***	*	NS	NS

CP– crude protein; FN – falling number; WA – water absorption; DDT – dough development time; DS – dough stability; SD – softening of dough; MTI – mixing tolerance index; TGW – thousand grain weight; FU – farinograph units; F – fertilised; NF – non-fertilised

Mean values and standard deviations shown, influence of factors system, fertilisation treatment, growing year and interaction system × fertilisation provable at *P < 0.05, **0.01, and ***0.001, respectively; NS – non-significant; $^{a-d}$values in a column followed by different letters are significantly different at P < 0.05

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Table 4. Mixolab parameters in relation to protein and starch characteristics (n = 32)

System	Stability (min)	C2 (Nm min^{-1})	C3	C4 (Nm)	C5	α	β (Nm min^{-1})	γ
Organic	6.01^{a}	0.51	1.91^{b}	1.94^{a}	3.82^{a}	−0.07^{a}	0.51^{a}	9×10^{-4b}
Integrated	4.78^{b}	0.50	1.95^{a}	1.72^{b}	2.72^{b}	−0.03^{b}	0.37^{b}	−0.05^{a}
Mean ± standard deviation	5.39 ± 2.68	0.50 ± 0.05	1.93 ± 0.22	1.83 ± 0.45	3.27 ± 1.53	−0.05 ± 0.03	0.44 ± 0.12	−0.03 ± 0.04
P system	***	NS	*	**	***	**	**	**
Fertilisation								
F	7.86^{a}	0.53^{a}	1.98^{a}	1.82	3.09^{b}	−0.05	0.46^{a}	−0.04^{a}
NF	2.93^{b}	0.48^{b}	1.89^{b}	1.83	3.46^{a}	−0.05	0.42^{b}	−0.01^{b}
P fertilisation	***	***	**	NS	**	NS	*	**
Year								
2015	4.88^{b}	0.55^{a}	2.13^{a}	2.21^{a}	4.45^{a}	−0.04^{b}	0.49^{a}	-4×10^{-4b}
2016	5.91^{a}	0.46^{b}	1.74^{b}	1.45^{b}	2.09^{b}	−0.07^{a}	0.39^{b}	−0.05^{a}
P year	**	***	***	***	***	*	**	**
System × fertilisation								
Organic F	8.83^{a}	0.53^{a}	1.98^{a}	1.88^{ab}	3.34^{b}	−0.07	0.53	−0.02^{c}
Integrated F	6.89^{b}	0.53^{a}	1.98^{a}	1.77^{bc}	2.83^{c}	−0.04	0.38	−0.05^{a}
Organic NF	3.19^{c}	0.48^{b}	1.85^{b}	2.01^{a}	4.30^{a}	−0.07	0.49	0.03^{b}
Integrated NF	2.67^{d}	0.47^{c}	1.93^{a}	1.66^{c}	2.61^{d}	−0.03	0.35	−0.05^{a}
P system × fertilisation	**	*	*	*	***	NS	NS	**

C2 – protein weakening; C3 – starch gelatinisation; C4 – amylolytic activity; C5 – starch retrogradation; α – speed of protein weakening; β – gelatinisation speed; γ – α-amylase degradation speed; F – fertilised; NF – non-fertilised

Mean values and standard deviations shown, influence of factors system, fertilisation treatment, growing year and interaction system × fertilisation provable at P < *0.05, **0.01, and ***0.001, respectively; NS – non-significant; [a–d]values in column followed by different letters are significantly different at P < 0.05

https://doi.org/10.17221/189/2020-CJFS

Table 5. Correlation coefficients between quality indicators of winter wheat

	C3	C4	C5	β	γ	FN	WA	DDT	DS	SD	MTI
C2	0.86	0.69	0.58	NS	NS	0.80	NS	NS	0.60	–0.73	–0.74
α	NS	NS	NS	NS	NS	NS	NS	–0.56	NS	NS	NS
C3	–	0.83	0.65	NS	NS	0.77	NS	NS	NS	–0.55	–0.55
C4	–	–	0.94	0.53	0.81	0.81	NS	NS	NS	–0.52	NS
C5	–	–	–	0.72	0.89	0.76	NS	NS	NS	NS	NS
β	–	–	–	–	0.58	NS	NS	NS	NS	NS	NS
γ	–	–	–	–	–	0.65	NS	NS	NS	NS	NS
FN	–	–	–	–	–	–	NS	NS	0.57	–0.77	–0.63
WA	–	–	–	–	–	–	–	NS	0.74	–0.72	–0.73
DDT	–	–	–	–	–	–	–	–	NS	NS	NS
DS	–	–	–	–	–	–	–	–	–	–0.81	–0.91
SD	–	–	–	–	–	–	–	–	–	–	0.89

C2 – protein weakening; C3 – starch gelatinisation; C4 – amylolytic activity; C5 – starch retrogradation; α – speed of protein weakening; β – gelatinisation speed; γ – α-amylase degradation speed; FN – falling number; WA – water absorption; DDT – dough development time; DS – dough stability; SD – softening of dough; MTI – mixing tolerance index
Correlations are significant at $P < 0.01$; NS – not significant

torque C2, C3, C4, C5 values of 0.60, 1.98, 1.90, and 2.97 Nm, respectively. Starch properties of ORG winter wheat, when organic fertiliser was used, demonstrated Mixolab rheological behaviour of flour dough equivalent to the standard flour. There is poor availability of data on the effect of the cropping system on rheological Mixolab parameters of wheat. Still, Podolska et al. (2020) reported an important influence of the share of cereals in crop rotation on the grain and dough quality, with a decrease of alveograph value "W" with an increased share of cereals. Babulicová and Gavurníková (2015) found higher wet gluten content and gluten index in crop rotations with a lower share of cereals.

Correlation analysis. Pearson's correlation coefficients between the quality parameters under study were determined (Table 5). Torque C2 correlated to all analysed torque values C3, C4, C5 (r between 0.86–0.58). Significant links to farinograph DS, SD, MTI (r between 0.74–0.60) were found. C3 parameter can be predicted according to the C2; the strongest correlation was proved (r = 0.86). Švec and Hrušková (2015) reported torque C2 as the most independent, less exchangeable parameter of the Mixolab, with a strong correlation to C3 (r = 0.86). In our study, the highest relation (r = 0.94) was observed between the C4 and C5; comparable relationships were reported by Papoušková et al. (2011), with r = 0.93. Farinograph WA was the most independent parameter, and any significant correlations to other rheological parameters were determined. Strong relation was observed between FN and most of the Mixolab parameters. Also, Banu et al. (2011) found that the changes of the Mixolab curve trend depended on the FN value and correlated with the results of the baking test.

CONCLUSION

The presented study provides a better understanding of the long-term effect of cropping systems on rheological quality traits of winter wheat and its productivity. The well-designed and adapted cropping system to soil, climate, and external plant nutrition sources has important implications on production and product quality parameters with an impact on farmers, processors, and consumers. Replacement of chemical inputs in an organic system for a more diversified crop rotation, higher share of N-fixing crops and use of certified nutrition sources resulted in consistent, high-quality grain yields of winter wheat with lower reliance on external inputs.

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