https://doi.org/10.46909/journalalse-2021-036
Available online: https://jurnalalse.com

Original Article
Journal of Applied Life Sciences and Environment
Vol. LIV, Issue 4 (188) / 2021: 417-428

WINTER WHEAT MIXTURES INFLUENCE GRAIN RHEOLOGICAL AND MIXOLAB QUALITY

Trong Nghia HOANG[1,2*], Marek KOPECKÝ[1], Petr KONVALINA[1]

*E-mail: hoangn00@fzt.jcu.cz

Received: June 06, 2022. Revised: June 24, 2022. Accepted: June 27, 2022. Published online: July 08, 2022

ABSTRACT. This study aims to investigate the effect of a mixture of winter wheat varieties on grain rheological characteristics and the quality of wheat flour analyzed by Mixolab. In the 2019-2020 growing season, a small plots experiment was carried out in an organically certified field in the Czech Republic. The experiment was conducted by randomized complete block design with three replicates, four winter wheat (*Triticum aestivum* L.) varieties with four mixtures of the same varieties in equal proportions. Based on the results, the expected grain yield was not achieved. The quality of wheat productivity was significantly different among treatments in terms of protein content, wet gluten, sedimentation value, and falling number ($P < 0.001$). Protein content ranged between 8.04% and 9.85%, mixtures of Butterfly + Lorien and Illusion + Lorien were higher in protein than Illusion and Vanessa varieties and their combination. The highest wet gluten was found under mixtures of Butterfly + Lorien varieties (19.34%) while sowing Butterfly variety gave the highest Zeleny test and falling number compared to other treatments. Butterfly + Lorien and Butterfly + Vanessa mixtures obtained good results for falling number at 250.67 and 272.67 seconds. There were significant differences in rheological quality parameters of winter wheat varieties analyzed by Mixolab including stability, weakening of protein, and starch ($P < 0.01$ and $P < 0.001$, except slope gamma). Although the observed benefits were limited to grain yield, mixtures of individual cultivars appear to be a potential tool to improve overall crop performance (grain quality).

Keywords: baking quality, organic farming, yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most common cereal consumed worldwide behind maize. In particular, demand for organic wheat has increased in recent years. Organic farming is being fuelled not only by concerns about the stability and balance of the environment and economy but also by increased consumer understanding of food safety. According to ORG_CROPAR

[1] Department of Agroecosystems, Faculty of Agriculture and Technology, University of South Bohemia in Ceske Budejovice, Studentska 1668, 37005 Ceske Budejovice, Czech Republic
[2] University of Agriculture and Forestry, Hue University, Hue City, Vietnam

(2022), the EU's total organic area was 14.7 million hectares, up 5.2 million hectares in the ten years from 2012. The organic area increased by 56% between 2012 and 2020. Accompanying the development of organic agriculture in the world in general and in Europe in particular, Czech Republic's agricultural policy is oriented toward organic farming, which provides both environmental protection as well as social and economic advantages. In 2019, the certified area of organic common wheat production in the Czech Republic amounted to 13,732 hectares of a total of 40,908 hectares of grain cereals, occupying about 2% of the total global area of wheat (Mie *et al.*, 2017; Yearbook, 2019).

Organic farming methods are distinguished by low soluble nitrogen availability, particularly in early spring nutrient absorption and use. Wet soil and cold temperatures in early spring limit microbial activity, and the mineralization process in the soil influences plant growth. In organic farming systems, the comparatively low nitrogen availability affects winter wheat yields, grain protein, and the quality of baking wheat flour (Cesevicienе *et al.*, 2009; Konvalina *et al.*, 2009). In organic farming, organic yields are often 14% lower (Mäder *et al.*, 2007), or even 30% to 70% lower (Kaut *et al.*, 2008). Konvalina *et al.*, (2009) and Osman *et al.*, (2012) found grain yield 20–50% lower and protein content 10–25% lower than conventional farming. Wheat grain quality is not only dependent on weather conditions, the varieties play a role in organic growing (Cesevicienе *et al.*, 2009).

Organic agriculture's priorities are increasing grain yield and increasing the quality of rheological characteristics of winter wheat varieties. Different varieties are suitable for different environments, and efforts in breeding and selection may improve outcome and baking quality to a certain extent. These, however, take a long time and are expensive. A complementary solution may be the development of alternative farming methods. Mixtures of cultivars may help to stabilize yields and increase the quality of wheat (Cesevicienе *et al.*, 2009; Konvalina *et al.*, 2009; Vrtilek *et al.*, 2016; Vidal *et al.*, 2020; Lacko-Bartošová *et al.*, 2021).

Wheat variety mixtures can assist stability and boost yield as well as help to attain high results in bread quality compared to individual components (Aart, 2006; Kaut *et al.*, 2008, 2009). Moreover, the diversity created using mixes of varieties may boost resistance to fungal infections while also limiting their appearance and spread in plant populations compared to varieties grown in a monoculture.

Environmental friendliness is another benefit that should not be overlooked. Parallel planting of two winter wheat varieties that complement each other in traits such as high and low tolerance to frost, drought, diseases, and lodging boosts the inter-annual stability of yields and quality of output (Vrtilek *et al.*, 2016; Vidal *et al.*, 2020).

The study aimed to evaluate the grain yield and quality characteristics of wheat flour of winter wheat varieties mixtures under the conditions of organic agriculture.

MATERIALS AND METHODS

Field experiment

The small plot experiment was conducted in a certified organic field (48.973995N, 14.612085E) in Zvikov, Ceske Budejovice, Czech Republic in the 2019–2020 growing season. The soil texture was loamy, and the weather condition was mild warm climate, at an altitude of 460 m.

The total annual rainfall was 634 mm. Some climate data for the years from 1989 to 2019 and the 2019 – 2020 growing season are given in *Table 1*.

Table 1 - Monthly climate data for the 2019 – 2020 growing season and previous years in Ceske Budejovice

Month	Temp. Mean (°C)	1989 - 2019*	Precipitation (mm)	1989 – 2019**	HC
September	12.4	12.37	50.6	56.87	1.36
October	7.5	7.71	33.9	47.26	1.50
November	2.4	2.85	38.6	42.35	5.36
December	-1.0	-0.73	30.2	40.65	-10.06
January	-2.7	-1.59	26.5	40.29	-3.27
February	-1.1	-0.61	27.1	32.58	-8.21
March	2.4	3.03	34.4	45.77	4.77
April	6.9	7.70	48.6	41.00	2.34
May	11.9	12.55	76.7	73.00	2.14
June	15.2	15.97	99.2	88.87	2.17
July	16.8	17.66	84.6	92.48	1.67
August	16.1	17.22	83.3	82.94	1.72
Mean	7.23	7.84	52.81	57.01	-
Total	86.80	94.13	633.70	684.06	-

*Average temperature between 1989 and 2019, **Average precipitation from 1989 to 2019 in Ceske Budejovice, HC: Hydrothermal coefficient.

In the experiment, the trial variants were evaluated in experiments using mixtures of winter wheat varieties as follows: Butterfly, Illusion, Lorien and Vanessa sown as single crops; the mixture of two varieties (50% sharing) with Butterfly + Lorien, Butterfly + Vanessa, Illusion + Lorien, and Illusion + Vanessa. The experiment was conducted using a randomized complete block design with three replicates. The preceding crop was red clover (*Trifolium pretense* L.). The fertilization applied was 4 t ha^{-1} of composted sheep manure. Winter wheat was mechanically sown in 12.5 cm spaced rows. All treatments were harvested from the field and treated at the Faculty of Agriculture and Technology, University of South Bohemia in Ceske Budejovice, Czech Republic.

Evaluation of qualitative parameters

Wheat milling

The wheat flour samples were milled by PSY 20 (Mezos, Hradec Kralove, Czech Republic) and Quadrumat Junior machine (Brabender, Duisburg, Germany).

The baking quality

Protein content (%)

Protein content (PC) was determined by Kjeltec 1002 System (Tecator AB, Hoganas, Sweden), based on N * 5.7 (in dry matter).

Wet gluten (%)

According to ICC Standard No. 137/1, wet gluten (WG) was measured by Glutomatic 2200 and Centrifuge 2015 (Perten Instruments, Hägersten, Sweden).

Sedimentation value (ml)

According to the ICC standard No. 116/1, the sedimentation value (Zeleny test) (ZSV) was determined using SDZT4 apparatus.

The falling number (s)

According to ICC standard No. 107/1, AACC International method 56-81B, the falling number (FN) was measured using FN 1100 (Perten Inst., Sweden). Evaluation of the falling number is shown in *Table 2*.

The thermo-mechanical properties

According to the ICC standard method No. 173 - ICC 2006, Mixolab was used to assess the wheat flour's rheological properties, including the dough during mixing, as well as the quality of starch and protein. The Mixolab curves from wheat flour. Amplitude: Elasticity of the dough (the higher the value, the more elastic the flour); Stability: Resistance to dough kneading (the longer the duration, the stronger the flour); Torque C2: Attenuation of protein due to mechanical work and temperature; Torque C3: The gelatinization of starch; Torque C4: Stability of hot gel; Torque C5: Measured retrogradation of starch in the cooling phase; Slope α (C1–C2): Attenuating rate of protein in warming; Slope β (C2–C3): starch gelatinization rate; Slope γ: (C3–C4): Enzymatic degradation rate. The parameters evaluated by Mixolab are illustrated in *Fig. 1*, in which five stages can be distinguished.

Table 2 - The evaluation of falling number parameter

Values (s)	Enzymatic activity	Baking properties
< 150	High	Viscous crumb of bread
200 – 300	Optimal	Very good crumb of bread
> 300	Low	Dry crumb of bread, reduced loaf volume

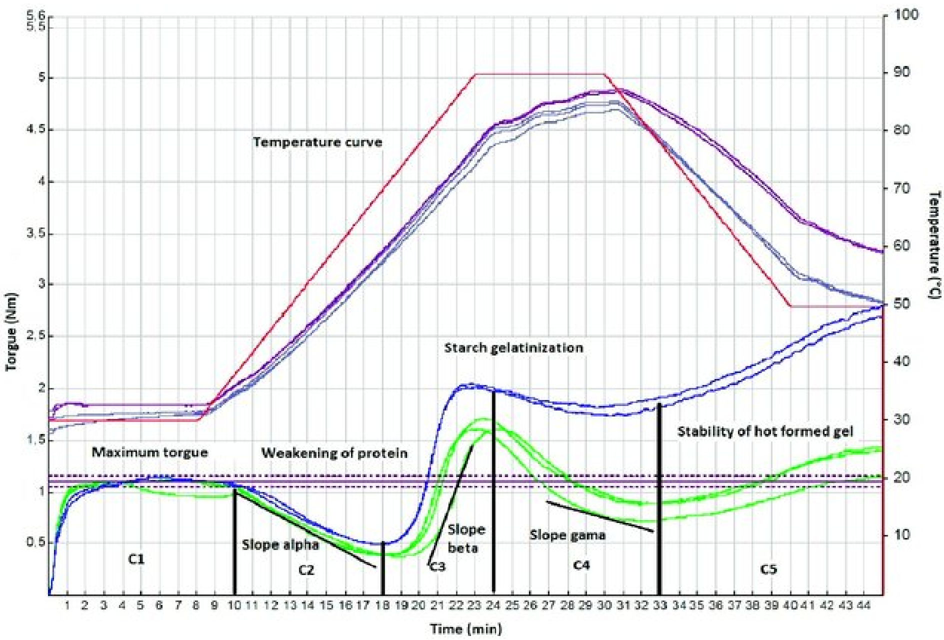

Figure 1 - The Mixolab curves from wheat flour

Statistical analysis

The STATISTICA application (version 13.2, StatSoft, Inc., California, USA) was used to analyze the data. For variance analysis, a one-way ANOVA was performed. Tukey's honest significant difference (HSD) was used to find significantly different mean values at the probability levels of $P < 0.05$, $P < 0.01$, and $P < 0.001$.

RESULTS AND DISCUSSION

Grain yield

Table 3 shows that grain yield differed statistically between treatments ($P < 0.01$), with higher values in the single cultivar compared with cultivar mixtures. Illusion and Vanessa are the varieties that showed the highest yield by 9.44 t ha^{-1} and 9.73 t ha^{-1}, respectively. Illusion + Lorien and Butterfly + Lorien were lowest at 5.77 t ha^{-1} and 5.95 t ha^{-1} while the combination of Illusion + Vanessa and Butterfly + Vanessa indicated no difference compared to the single variety. Illusion + Vanessa and Butterfly + Vanessa mixtures may have improved grain yield potential. Cowger *et al* (2008) and Mundt *et al.* (1995) reported an average yield increase in winter wheat mixtures but yield increases were relatively small. Similarly, there was no significant difference between single and combination of winter wheat in the study of Chen *et al.* (2020) of 4.06 t ha^{-1}. For organic spring wheat cultivation, Dai *et al.* (2012) found that the cultivar mixture did not improve grain yield. In other studies, grain yield was lower than in our experiment in organic winter wheat cultivation (Jablonskytė-Raščė *et al.*, 2013; Lazzaro *et al.*, 2018; Tran *et al.*, 2020). Wheat grain production may be influenced by agronomic features, cultivation practices, and other factors. Although the grain yield was limited, the winter wheat combination may offer advantages in baking traits and rheological quality when using mixtures of individual cultivars under different conditions.

Table 3 – Grain yield and baking quality of winter wheat grain

Varieties	Yield (t ha^{-1})	Protein (%)	WG (%)	ZSV (ml)	FN (s)
Butterfly	7.54±0.80^{abc}	9.85±0.25^{a}	16.66±1.14^{df}	28.42±0.80^{a}	310±6.08^{a}
Lorien	8.87±1.42^{ab}	9.23±0.24^{abc}	17.31±0.12^{cd}	21.00±3.00^{a}	248±5.03^{c}
Illusion	9.44±0.60^{a}	9.08±0.27^{bc}	18.01±0.07^{bc}	21.00±3.00^{a}	226±2.65^{d}
Vanessa	9.73±0.59^{a}	8.04±0.22^{d}	4.44±0.47^{h}	7.25±0.75^{c}	261±6.11^{bc}
Bu+Lo	5.95±1.10^{bc}	9.60±0.41^{ab}	19.34±0.03^{a}	25.50±6.50^{a}	250±7.02^{c}
Bu+Va	6.96±0.20^{abc}	9.13±0.00^{abc}	14.76±0.22^{g}	20.00±2.00^{ab}	272±4.04^{b}
Illu+Lo	5.77±1.71^{c}	9.44±0.26^{ab}	18.84±0.11^{ab}	22.50±1.50^{a}	223±2.08^{d}
Illu+Va	7.25±1.34^{abc}	8.59±0.20^{cd}	15.38±0.19^{fg}	12.00±2.00^{bc}	209±4.00^{e}
P	**	***	***	***	***

Means ± standard deviation (n= 3), different letters within the column show statistically significant difference at $P < 0.05$, Tukey HSD test. * < 0.05, ** < 0.01, *** < 0.001. Mixtures of winter wheat varieties: Bu + Lo: Butterfly + Lorien, Bu + Va: Butterfly + Vanessa, Illu + Lo: Illusion + Lorien, Illu + Va: Illusion + Vanessa. FN: Falling number, ZSV: Sedimentation value (Zeleny test), WG: wet gluten.

Wheat quality

Table 3 shows a highly significant statistical difference (*P < 0.001*) for the productivity and wheat quality in terms of protein content, wet gluten, sedimentation value, and falling number.

Wheat protein content is a factor to consider when making bread, protein content varies depending on wheat variety, growing area, soil type and quality, and fertilizer input (type, amount and time), particularly nitrogen. According to Chen *et al.* (2020), the protein content was lower in organic farming than conventional farming. Protein content was higher under mixtures of two varieties but the increases were relatively small (0.2%) compared to wheat varieties grown singly in an organic system. Similarly, Krejčířová *et al.* (2008) reported protein content was higher in conventional (11.04%) compared to organic farming (9.48%). The protein content in their paper on organic farming is close to our results (9.12%), while protein content was 1.92% higher in conventional agriculture. Lazzaro *et al.* (2018) also found that mixtures of cultivars improved grain protein quality. On the other hand, there was no difference in protein between mixtures and pure line cultivars (Gallandt *et al.*, 2001). Protein content was significantly different (*Table 3*), ranging from 8.04% to 9.85%, and increases were relatively small in mixtures (0.14% higher). The single Butterfly variety (9.85%), and the combinations of Butterfly + Lorien (9.60%), Illusion + Lorien (9.44%), and Butterfly + Vanessa (9.13%) were higher than Illusion and Vanessa single varieties, and their combination giving 9.08%, 8.04%, and 8.59%, respectively. The combination might improve protein content compared to individual varieties.

Wet gluten, sedimentation value (Zeleny test) and falling number are characteristics important for bread baking. Wet gluten was significantly different (*P < 0.001*), with the highest wet gluten under the combination of Butterfly + Lorien (19.34%), followed by mixtures of Illusion and Lorien (18.84%). The combinations of Butterfly + Vanessa and Illusion + Vanessa were lower than the single variety with 14.76% and 15.38%, respectively. On average, gluten proteins of mixtures were higher (17.08%) than sowings of a single wheat seed variety (14.10%). The average wet gluten number in our experiment (15.59%) was lower than that found by Jablonskytė-Raščė *et al.* (2013) (24.53%) and Krejčířová *et al.* (2008) (18.59%), and two times lower than that in Tran *et al.* (2020) (30.87%). In order to obtain the expected yield and quality parameters, the right selection of bread wheat crops is essential because the quality of wet gluten is influenced by the interaction of variety - environmental conditions.

Regarding sedimentation, its values usually correlate positively with the protein content and the volume of baked bread. At high sedimentation values, high volume breads are obtained. The evaluation of sedimentation value characteristics indicated the same between the average of single and mixtures by 19.42 and 20.00 ml. However, a higher significant difference was apparent when comparing individual varieties with each of their mixtures (*P < 0.001*). Sedimentation value was highest when growing only Butterfly (28.42 ml), followed by single varieties Lorien and Illusion and their mixtures, ranging from 21 to 25.5 ml. Vanessa winter wheat variety and its mixtures with Illusion were the lowest, only 7.25 ml and 12.00 ml. Aart (2006) indicated that the performance of the other mixtures for Zeleny-sedimentation value was equal to the mean of the individual varieties but higher than in our experiment.

The falling number test is used to assess the level of sprout damage in wheat and negatively correlates with alpha-amylase (an enzyme found in sprout-damaged wheat), with a significant increase in this enzyme if germination occurs. The level of alpha-amylase in wheat increases, and the number of tests will decrease. Values below 150 s indicate strong alpha-amylase activity, while values over 300 s imply low α-amylase activity, with an optimal falling number range of 250-280 s. A high falling number or a longer time implies that the wheat is better suited for most baking (Wang et al., 2008). The falling number of all analyzed winter wheat samples ranged from 209 to 310 s. The differences between species were significant. Falling number of the combinations Butterfly with Vanessa (272.67 s) and Butterfly with Lorien (250.67 s) were higher than single and mixtures of Lorien and Illusion varieties. Therefore, the combination of wheat varieties may improve their baking quality in low-input agriculture conditions.

Mixolab analysis

The advantage of Mixolab is being able to measure the flour characteristics of cereals in one test including proteins, starch and associated enzymes. The mean values of each treatment for stability, Torque C2, Torque C3, Torque C4, Torque C5 and slopes α, β and γ are displayed in *Table 4* and *Fig. 2*. Regarding the mixing resistance of dough, the longer this time is, the more the flour will be strong. The value of stability normally ranges from 4.96 to 11.42 minutes. *Table 4* shows that the stability assessed by Mixolab for winter wheat varieties and mixtures ranged between 4.37 and 6.37 minutes, and was highly significant (*P < 0.001*). The values of stability of mixtures of Butterfly (6.20 min) and Butterfly + Lorien (6.37 min) were the longest, followed by single sown Vanessa variety sown seed single and Illusion + Vanessa mixtures that were 5.30 min and 5.33 min, respectively. Other single varieties and mixtures were lower than the ranges normal for stability. The combinations of winter wheat varieties affected the stability of winter wheat flour. According to Lacko-Bartošová *et al.* (2021), growing winter wheat in organic farming (8.83 min) and Tran *et al.* (2020) (9.76 min) the stability was higher than in our results (5.14 min). However, a lower stability value when growing winter wheat organically without fertilizer of 3.19 min was found in the study of Lacko-Bartošová *et al.* (2021). Different cultivation conditions affected the resistance to dough kneading of wheat flour.

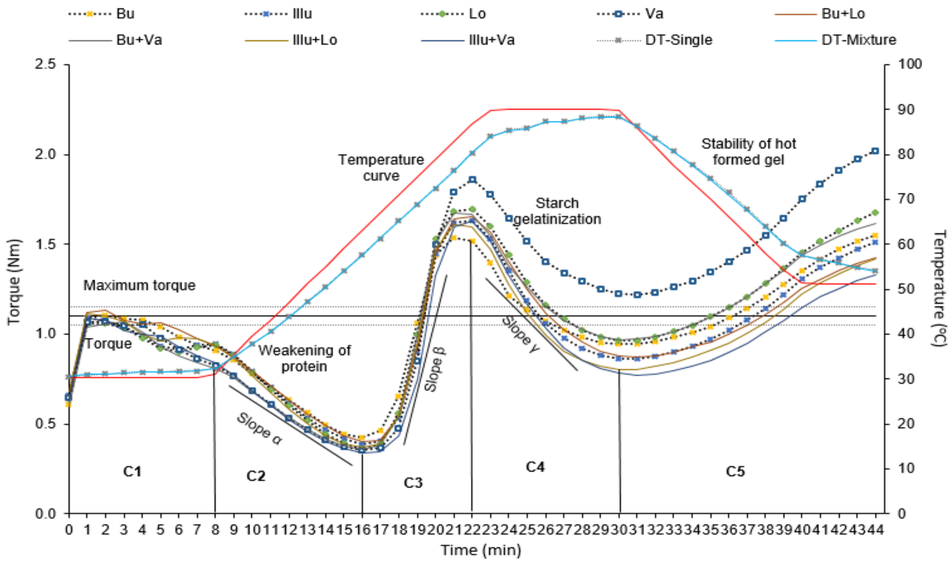

Figure 2 - Mixolab curves of milled flour

Wheat variety: Bu: Butterfly, Lo: Lorien, Illu: Illusion, Va: Vanessa. Mixtures of winter wheat varieties: Bu + Lo: Butterfly + Lorien, Bu + Va: Butterfly + Vanessa, Illu + Lo: Illusion + Lorien, Illu + Va: Illusion + Vanessa. DT_Single: average dough temperature among single varieties, DT_Mixture: average dough temperature among winter wheat mixtures.

During the second phase, Torque C2 (protein weakening) and slope alpha (protein network weakening speed) parameters were obtained. Strong wheat flour has a Torque C2 value higher than 0.4 Nm. If this number is between 0.5 and 0.6 Nm, it indicates high protein quality, a higher ability of gluten to resit heating, and stronger gluten network, according to Lacko-Bartošová *et al.*, (2021). There was a positive correlation between wet gluten and Torque C2 but no significant difference (r = 0.38) (*Table 5*).

The value of Torque C2 torque analyzed in our study was lower than 0.4 Nm (except for Butterfly, 0.42 Nm), and the average number of Torque C2 was lower than the results indicated above. Torque C2 ranged from 0.33 Nm to 0.42 Nm, the highest displayed for Butterfly variety sown singly (0.42 Nm), the weakening of protein of Lorien as a variety single crop was lower; however, mixtures with Butterfly showed Torque C2 (0.39 Nm) higher than with other treatments.

The slope α, related to protein thermal weakening and indicative of dough strength (Leszek *et al.*, 2016), was significantly dependent on single and mixture components. The lower slope α confirmed lower protein quality (Lacko-Bartošová *et al.*, 2021). The slope α of Illusion and Lorien mixtures was lower than other treatments. The combinations of Butterfly with Lorien, Butterfly with Vanessa and Illusion with Vanessa were not significantly different compared to winter wheat varieties sown singly, ranging from -0.07 to -0.09. The average number of slope α was not significant compared to other studies such as Lacko-Bartošová *et al.* (2021); Leszek *et al.* (2016); Tran *et al.* (2020).

Starch characteristics were significantly different ($P < 0.001$) in growing single and winter wheat varieties mixtures. Gelatinization (Torque C3) ranged from 1.55 to 1.87 Nm, amylolytic activity (Torque C4) ranged between 0.77 and 1.21 Nm, and retrogradation (Torque C5) showed between 1.34 and 2.04 Nm. The Vanessa variety was highest compared to other individual and combinations of varieties by 1.87 Nm, 1.21 Nm and 2.04 Nm for C3, C4 and C5, respectively. On the other hand, the mixtures between varieties can improve each other. The combination of Butterfly and Vanessa varieties showed higher Torque C3 (1.70 Nm), Torque C4 (0.96 Nm), and Torque C5 (1.63 Nm).

Regarding the speed of gelatinization of the starch, the configuration of the slope γ shows that in conditions of continuous heating of the dough and the constant speed of mixing, the processes of protein denaturation and gelatinization of the starch have stopped. Maximum torque during the heating stage starch gelatinization did not statistically differ among varieties, and their combination ranged between -0.11 and -0.07.

Correlation coefficients among grain yield, baking quality, and rheological parameters analyzed by Mixolab under study were determined (*Table 5*). Weather conditions influenced grain yield and wheat quality.

Table 4 – Rheological parameters were evaluated by Mixolab

Varieties	Stability (min)	Alpha	Beta	Gamma
Butterfly	6.20±0.20[a]	-0.07±0.00[ab]	0.44±0.02[bc]	-0.13±0.06
Lorien	4.50±0.26[d]	-0.09±0.01[bc]	0.52±0.03[b]	-0.11±0.02
Illusion	4.43±0.06[d]	-0.08±0.01[abc]	0.43±0.05[c]	-0.13±0.01
Vanessa	5.30±0.10[bc]	-0.07±0.00[a]	0.62±0.01[a]	-0.07±0.02
Bu+Lo	6.37±0.29[a]	-0.09±0.01[abc]	0.51±0.03[bc]	-0.11±0.04
Bu+Va	4.60±0.17[cd]	-0.08±0.01[abc]	0.61±0.04[a]	-0.11±0.01
Illu+Lo	4.37±0.40[d]	-0.09±0.00[c]	0.46±0.01[bc]	-0.12±0.01
Illu+Va	5.33±0.32[b]	-0.09±0.01[abc]	0.47±0.02[bc]	-0.12±0.01
P	***	**	***	*NS*

Varieties	Torque C2 (Nm)	Torque C3 (Nm)	Torque C4 (Nm)	Torque C5 (Nm)
Butterfly	0.42±0.00[a]	1.55±0.01[e]	1.03±0.10[b]	1.56±0.90[bcd]
Lorien	0.36±0.01[c]	1.71±0.02[b]	0.96±0.03[bc]	1.69±0.06[b]
Illusion	0.38±0.00[b]	1.65±0.01[cd]	0.85±0.02[cd]	1.53±0.03[cd]
Vanessa	0.35±0.00[cd]	1.87±0.03[a]	1.21±0.08[a]	2.04±0.10[a]
Bu+Lo	0.39±0.01[b]	1.67±0.02[bcd]	0.87±0.02[cd]	1.44±0.04[de]
Bu+Va	0.36±0.01[c]	1.70±0.03[bc]	0.96±0.05[bc]	1.63±0.07[bc]
Illu+Lo	0.36±0.00[c]	1.62±0.00[d]	0.80±0.01[d]	1.43±0.01[de]
Illu+Va	0.33±0.00[d]	1.64±0.01[cd]	0.77±0.01[d]	1.34±0.01[e]
P	***	***	***	***

Means ± standard deviation (n= 3), different letters within the column show statistically significant difference at $P < 0.05$, Tukey HSD test. *NS* – Non significant, * < *0.05*, ** < *0.01*, *** < *0.001*.
Mixtures of winter wheat varieties: Bu + Lo: Butterfly + Lorien, Bu + Va: Butterfly + Vanessa, Illu + Lo: Illusion + Lorien, Illu + Va: Illusion + Vanessa.

Table 5 - The coefficient of correlation between quality parameters of winter wheat was significant at *P < 0.05 and *P < 0.01***

	P (%)	WG (%)	ZSV (ml)	FN (s)	C2 (Nm)	C3 (Nm)	C4 (Nm)	C5 (Nm)	α	β	γ	Stability (min)
Yield	-.49*	-.49*	-.44	.06	-.11	.46*	.26	.58**	.22	.19	.21	-.22
P	-	.76**	.97**	.31	.72**	-.73**	-.53**	-.49*	-.24	-.47*	-.37	.23
WG		-	.75**	-.20	.38	-.80**	-.50*	-.82**	-.58**	-.66**	-.49*	-.04
ZSV			-	.33*	.77**	-.69**	-.41*	-.42*	-.21	-.46**	-.29	.22
FN				-	.60**	-.06	.11	.40	.63**	.26	.10	.44*
C2					-	-.50*	-.28	-.11	.14	-.41*	-.15	.51*
C3						-	.66**	.82**	.26	.78**	.60**	-.15
C4							-	.63**	.29	.57**	.71**	-.15
C5								-	.50*	.68**	.58**	-.09
α									-	.46*	.24	.31
β										-	.53**	-.08
γ											-	.02

P: Protein, WG: Wet gluten, ZSV: Sedimentation value (Zeleny test), FN: Falling number. C1: Torque C1 –, C2: Torque C2 – protein weakening, C3: Torque C3 – starch gelatinization, C4: Torque C4 – amylolytic activity, C5: Torque C5 – starch retrogradation, α: speed of protein weakening, β: gelatinization speed, γ: α-amylase degradation speed.

Ceseviciene *et al.,* (2009) showed that grain yield was lower but the quality was better under rather dry and warmer growing conditions. In the 2019–2020 growing season experiment, the suitable weather was an advantage for growing and high grain yield, however, the grain quality was lower. There was a negatively correlated between grain yield and protein content, and wet gluten ($r = –0.49$, $P < 0.05$, *Table 5*). Chen *et al.* (2020) indicated that grain yield was negatively correlated with protein content (r = -0.53) in conventional farming but was not in organic farming. Grain yield was positively correlated with all rheological quality evaluated by Mixolab, and was significantly different with torque C3 (r = 0.46, $P < 0.05$) and torque C5 (r = 0.58, $P < 0.01$), expectation stability (r = -0.02). Considering the strong relationship between protein content and wet gluten (r = 0.76, $P < 0.01$) and sedimentation test (r = 0.97, $P < 0.01$), there was no significant correlation with the falling number (r = 0.31). The relationship between the protein content and wet gluten content is in accord with the results of Konvalina *et al.* (2009) (r = 0.93). Wet gluten was positively correlated with sedimentation value (r = 0.75, $P < 0.01$). Baking quality (protein content, sedimentation and falling number) was found to be significantly positively correlated with Torque C2 (r = 0.60 - 0.77, $P < 0.01$) and negatively correlated with almost all other Mixolab parameters. There was no significant correlation between gluten content and Torque C2 (r = 0.38). The results indicated that the falling number was significantly correlated with slope alpha (r = 0.63, $P < 0.01$), and stability (r = 0.4, $P < 0.05$). The hydrolytic activity of alpha-amylase during the heating period, expressed by relationship between slope β and falling number, was not significant (r = 0.26). There was a highly negative significant correlation among protein content, wet gluten, and sedimentation with starch characteristics in terms of Torque C3, Torque C4 and Torque C5.

CONCLUSIONS

This study aims to evaluate the effects of changing cultivation practices on grain production, wheat quality and rheological quality features analyzed by Mixolab in organic farming. Based on the results, the grain yield of the varieties mixture was lower than a single component; however, the combination of wheat varieties played a role in improving their baking quality in terms of protein content, wet gluten, sedimentation value, as well as rheological quality analyzed by Mixolab. Hence, improving grain dough and baking properties under mixtures of winter wheat should be the subject of additional research to improve adaptation to low input cultivation conditions.

Acknowledgement. This study was supported by research project No. NAZV QK1910046 of the Ministry of Agriculture of the Czech Republic.

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