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The defense of the dissertation takes place on June 11^{st}, 2021 at 11 AM in the room of the Scientific Board of ZF JU in Ceske Budejovice.

You can get acquainted with the dissertation at the study department of the Faculty of Agriculture, University of South Bohemia in Ceske Budejovice.

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Abstrakt

Pšenice setá je jednou z hlavních tržních plodin ekologického zemědělství. Přetrvávajícím problémem je nedostatek informací o reakci odrůd na pěstitelský systém ekologického zemědělství. Z tohoto důvodu je potřebné uvést na trh odrůdy pšenice, které byly buď přímo šlechtěny pro systém ekologického zemědělství, nebo se jedná o odrůdy šlechtěné v konvenčních šlechtitelských postupech, ale pro ekologické zemědělce jsou k dispozici informace o agronomicky významných znacích a jakosti zrna. Dostatek informací o dostupných odrůdách tak dále přispěje k většímu zájmu o pěstování tržních plodin na orné půdě v ekologickém zemědělství.

Cílem disertační práce bylo posoudit a analyzovat agronomicky významné znaky a kvalitativní parametry zrna devíti odrůd pšenice seté, ozimé formy, pěstované v systému ekologického zemědělství. Přesné maloparcelkové pokusy byly založeny na dvou lokalitách, ve třech ročnících v Českých Budějovicích a ve Zvíkově. Během vegetačního období byly hodnoceny vybrané agronomicky významné znaky. Vybrané jakostní parametry zrna byly analyzovány v laboratoři podle standardních metodik.

Ze získaných výsledků byl patrný vliv lokality a průběhu ročníku na devět hodnocených odrůd pšenice seté, ozimé formy. Rozdíly v agronomicky významných parametrech a hodnocených znacích jakosti byly statisticky průkazné. Na základě analýzy hlavních komponent (PCA) dle těsnosti jejich pozic ke kvantitativním a kvalitativním parametrům v analýze hlavních složek, jako je výnos, obsah bílkovin, SDS test, číslo poklesu, gluten index, obsah mokrého lepku a reologické vlastnosti, zejména pak stabilita těsta, čas C2 doba vývoje těsta, torzní síla C2, torzní síla C3, torzní síla C4 a torzní síla C5, byly identifikovány odrůdy s vysokým výnosem nebo odrůdy s vysokou pekařskou jakostí, dále pak odrůdy s vysokým výnosem a současně odpovídající jakostí. Vyhodnoceny byly také korelační vztahy mezi jednotlivými znaky.

Klíčová slova: ekologické zemědělství, pšenice ozimá, agronomické významné znaky, pekařská jakost zrna, reologické vlastnosti, Mixolab.

Abstract

The wheat cultivar demand for organic farming has been increasing rapidly in the recent year, which requires breeders applying new selection methodologies to release new varieties suitable for organic agriculture. This has been fostering not only the expansion of wheat production organic farming areas, but also the rise market demand, growing interest in low-input agriculture for ecological reasons. In this dissertation, the main goal study was to assess and analyze the agronomic and quality characteristics of nine bread wheat cultivars cultivated in organic farming system in the south region of Czech Republic. Field experiments were set up in two locations namely Ceske Budejovice and Zvikov in three years to measure all agronomic traits, whilst the quality parameters were analyzed in the laboratory according to the standard methods. From the collected data, results revealed the effects of location, year, and the weather condition on nine varieties studied as well as the statistically significant differences of agronomic traits and quality parameters among nine varieties. Based on the proximity of their positions to the parameter quantitative and quality in the principal component analysis, such as yield, protein content, SDS test, the falling number, gluten index, wet gluten and the rheological properties namely the stability of dough, time C2, the dough development time, torque C2, torque C3, torque C4, and torque C5, either the cultivars having high yield or the good baking performance cultivars, or the cultivar having both high yield and good quality were identified, and depicted the correlation among them.

Key words: winter wheat, agronomic traits, quality traits, rheological properties, Mixolab, organic farming.

Introduction and the aim of dissertation

Wheat is plant grown on more land area than any other commercial crop. It is also one of three main cereal crops grown all over the world, together with rice and maize. *Triticum aestivum* L. belonging to the grass family Poaceae, domesticated over 9,000 years ago, is a cultigen. Wheat species are the most frequently grown crops in the organic farming system. However, all of them are not suitable for organic farming, the ones grown in marginal regions. Currently, a lot of alternative crops, including the marginal wheat species, have become attractive too. Such species have been bred neither to increase the yield rate nor for the intensive farming system. Although the baking quality is not high from the conventional point of view, these species have a lot of specific characteristics such as higher proportion of proteins, favorable composition of amino acids, and a high proportion of mineral elements. Products made of such wheat species are considered as the specialty productions with a higher added value at the market and they may be applied well (Konvalina et al., 2011). Along with the development of organic farming area, the demand for organic varieties have been developing fast. This requires breeders applying new selection methodologies and logistics to isolate competitive genotypes for organic systems, and make sure that the best key traits such as weed competitiveness, nutrient efficiency and resistance to seed borne diseases are evaluated. This has been promoted increasing market demand, growing interest in low-input agriculture for ecological reasons, and going up organic wheat production as well (Arterburn et al., 2012).

The aim of dissertation

The main goal of this dissertation was study on agronomic and quality characteristics of bread wheat varieties cultivated in organic farming system in the Czech Republic. The aims are presented in detail as below:

- To summarize knowledge about bread wheat cultivation, agronomic traits, nutritional composition, and technological quality parameters by using the available scientific literature data.

- To set up field experiments in three consecutive years to investigate and evaluate the agronomic traits.

- To analyze the basic parameters of baking quality such as protein content, wet gluten content, gluten index, SDS test, falling number, and rheological characteristics.

- To statistically analyze the data of field experiments.

- To highlight the potential wheat varieties in organic farming in the Czech Republic.

Materials and Methods

Field Experiment

The experimental material consisting of nine cultivars, were conducted from 2016 to 2019 in the southern Czech Republic at two sites, namely Ceske Budejovice (CB) and Zvikov (ZV). In Ceske Budejovice, the soil of experimental site was pseudo gley cambisols, kind of soil-loamy sand soil; the weather condition was mild warm climate; altitude of 388 m. In Zvikov, the soil of experimental site was loamy soil; altitude of 460 m. These experiments were carried out by using randomized complete block design with four replicates at each of the two sites.

Evaluation of Agronomy Characteristics

In this study, indexes were analysed including: The length of plant, the number of spikelets per m^2, thousand kernel weight (TKW), yield per hectare. Thousand kernel weight and yield per hectare were calculated at a humidity of 14 % (Curna, 2016).

The Baking Quality

Gluten Index were measured by Glutomatic 2200 and Centrifuge 2015 (Perten Instruments, Hagersten, Sweden) according to AACC 38 - 12A method (AACC 38-12 A., 2000a), ICC (International Association for Cereal Chemistry) 155 (ICC – Standard No. 155., 1994), and ICC 158 (ICC – Standard No. 158., 1995).

Wet Gluten Content (WGC), the amount of wet gluten contained at 14 % moisture of each 100 g flour, was measured by Glutomatic 2200 and Centrifuge 2015 (Perten Instruments, Hagersten, Sweden).

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

Sodium dodecyl sulphate (SDS) was analyzed in flour samples according to the method of Axford *et al.* (Axford *et al.*, 1978).

The falling number was determined by Perten Falling Number 1310 (Perten Instruments, Hagersten, Sweden) according to AACC 56 - 81 B and ICC

Standard 107/1(AACC 56 - 81 B, 2000b; ICC - Standard No. 107/1, 1995).

Mixolab II was used to evaluate baking quality according to the ICC standard method No. 173 - ICC 2006 (ICC - Standard No. 173, 2006), which allowed us to evaluate physical dough properties, such as dough stability or weakening, and starch characteristics in one measurement.

Statistical Analysis

Data were analyzed by using the Statistica 13 program (StatSoft. Inc., California, USA). Comparisons of mean varieties and their division into statistically different categories were conducted using the Tukey's honest significant difference (HSD) test with p-value < 0.01 and < 0.05 considered statistically significant. One-way ANOVA and factorial ANOVA were applied for variance analysis. Principal component analysis was used to assess the association between groups of variables and the differences among the study parameters.

Results and Discussion

The Impact of Environment Effects on Plant Height, the Number of Spikes per m^2, Thousand Kernel Weight, and Yield.

In the Table 1 and Table 2, the mean value of varieties significantly differed from year-to-year and locations. In details, an upward trend of plant height was witnessed from 2017 to 2019 by 18.87 cm. Also, the data in Zvikov was higher than in Ceske Budejovice. Analysis of variance of plant height (harvest year, $F = 695.29$, $p < 0.001$; location, $F = 119.43$, $p < 0.001$, species, $F = 179.25$, $p < 0.001$) was more influenced by harvest year, followed by species and location. The interaction of two factors (year × location, year × species, location × species), and the interaction of three factors (year × location × species) were significant at p value < 0.001 for Y × L and Y × S, and p value < 0.05 for L × S and Y × L × S. Similarly, an increasing tendency of the number of spikes per m^2 and yield were observed for three years. While the number of spikes per m^2 was more affected by harvest year ($F = 106.79$, $p < 0.001$, yield was more affected by location ($F = 1327.41$, $p < 0.001$). The yield in Zvikov was 1.72 ton higher than in Ceske Budejovice. This could be explained by the different environment between two locations. The ANOVA of the number of spikes per m^2 showed that there was more interaction between Y × L ($F = 23.94$, $p < 0.001$) than the others. The ANOVA of yield was not significant in the interaction of Y × L, and L × S, but significant for Y × L and Y × L × S with $p < 0.001$. Thousand kernel weight was a little different trend when compared to others in quantitative parameters. TKW increased in 2018 before witnessing a decrease in the next year. The analysis of variance of TKW were significant difference with p value < 0.001 for main effects, the interaction of two factors and three factors. Results from Table 1 and 2 indicated that location with $F = 128.55$ was more impacted than harvest year and species with $F = 117.88$, $F = 107.00$, respectively.

The independent of year and growing location, Figure 1 point outs the comparison of nine varieties. The plant height ranged from 61.75 ± 1.22 cm to 87.37 ± 2.77

cm and was statistically different among varieties. Wiwa cultivar had the highest plant height with 87.37 cm followed by Bernstein, KM 15 - 17, and Sultan, whereas Balitus and Gordian had the lowest one with 62.79 cm and 61.75 cm, respectively. To compare with the results of plant height in organic farming, our results is lower than that one of Konvalina *et al.*; and is nearly similar to the results of Gevrek and Atasoy (Gevrek and Atasoy, 2012; Konvalina *et al.*, 2011).

The number of spikes per m^2 of different varieties was not likewise the plant height. The group of cultivars having the highest number were Zeppelin, Gordian, Sultan, Penelope, and Bernstein with the number of spikes being 373.83 ± 11.94, 370.87 ± 13.12, 355.87 ± 13.93, 344.91 ± 10.26, and 343.37 ± 16.04, respectively. The lowest number of spikes per m^2 belonged to KM 15 - 17 (297.62 ± 12.94) and Wiwa (279.87 ± 10.58). In a study reported by Cox *et al.*, the number of spikes per m^2 of winter wheat ranged from 503 to 585 in organic farming, these findings are almost double higher than our results (Cox *et al.*, 2019).

Table 1: Means ± standard error (SE) for the effects of harvest year, location, and wheat species on plant height, the number of spikes per m^2, thousand kernel weight, and yield

	Plant height (cm)	Number of spikes per m^2	TKW (g)	Yield ($ton.ha^{-1}$)
Harvest year				
2017	64.90±0.74 c	296.38±6.51 c	41.01±0.32 c	2.82±0.12 c
2018	71.94±0.95 b	327.29±5.98 b	43.88±0.42 a	3.78±0.11 b
2019	83.77±1.52 a	391.47±8.85 a	42.00±0.34 b	4.55±0.13 a
Location				
ZV	75.82±1.25 a	362.66±7.24 a	43.18±0.32 a	4.58±0.09 a
CB	71.25±1.06 b	314.10±5.89 b	41.42±0.29 b	2.86±0.08 b

Mean values associated with different lowercase letters are significant different within each column analyzed by one-way ANOVA, Turkey's test, p value < 0.05. ns: Not significant. CB: Ceske Budejovice. ZV: Zvikov.

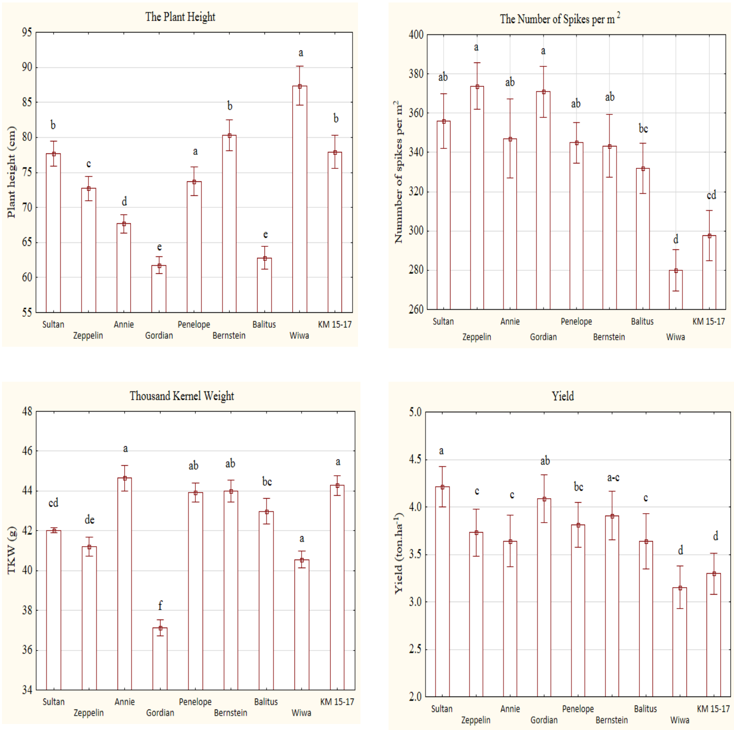
Table 2: ANOVA F-value for the effects of harvest year, location, and wheat species on plant height, the number of spikes per m2, thousand kernel weight, and yield

	Plant height (cm)	Number of spikes per m^2	TKW (g)	Yield ($ton.ha^{-1}$)
Main effects				
Harvest year (Y)	695.29**	106.79 **	117.88 **	450.17 **
Location (L)	119.43 **	80.30 **	128.55 **	1327.41 **
Species (S)	179.25 **	14.92 **	107.00 **	23.31 **
Interactions				
Y × L	27.14 **	23.94 **	29.79 **	2.48 (ns)
Y × S	12.47 **	2.60 *	9.86 **	2.79 **
L × S	3.47 *	2.07 *	7.66 **	0.78 (ns)
Y × L × S	2.63 *	2.32 *	7.26 **	3.61 **

ns: not significant, * *p value* < 0.05, **: *p value* < 0.001.

In spite of belonging to the lowest number of spikes per m^2, KM 15 - 17 cultivar together with Annie, Bernstein, and Penelope had the highest mean of TKW ranging from 44.28 ± 0.49 to 43.91 ± 0.48 g and were significantly difference, while Zeppelin and Wiwa had the lowest mean of TKW with 41.20 ± 0.46 g, 40.54 ± 0.42 g, respectively. These figures in our study are higher as compared to the results of other authors namely Konvalina *et al.*, Tran *et al.*, and Cox *et al.* (Cox *et al.*, 2019; Konvalina *et al.*, 2011; Tran *et al.*, 2020).

Figure 1: The agronomic characteristics of nine wheat varieties



The yield of studied cultivar varied between 3.15 ± 0.22 ton.ha^{-1} and 4.21 ± 0.21 ton.ha^{-1}. Sultan, Gordian, and Bernstein had the highest yield with 4.21 ± 0.21 ton.ha^{-1}, 4.09 ± 0.25 ton.ha^{-1}, and 3.90 ± 0.25 ton.ha^{-1}, respectively, vice versa was true for KM 15 - 17 (3.29 ± 0.21 ton.ha^{-1}) and Wiwa (3.15 ± 0.22 ton.ha^{-1}). The comparison of grain yield with different authors depicted that the yield of wheat cultivars in our experiments are lower than the findings of Cox et al. Ceseviciene et al., and Konvalina et al., whilst it is higher the results in previous study and over double higher than these one of Gevrek and Atasoy (Ceseviciene et al., 2009; Cox et al., 2019; Gevrek and Atasoy, 2012; Konvalina et al., 2011; Tran et al., 2020).

Flour Quality Parameters

The Protein Content

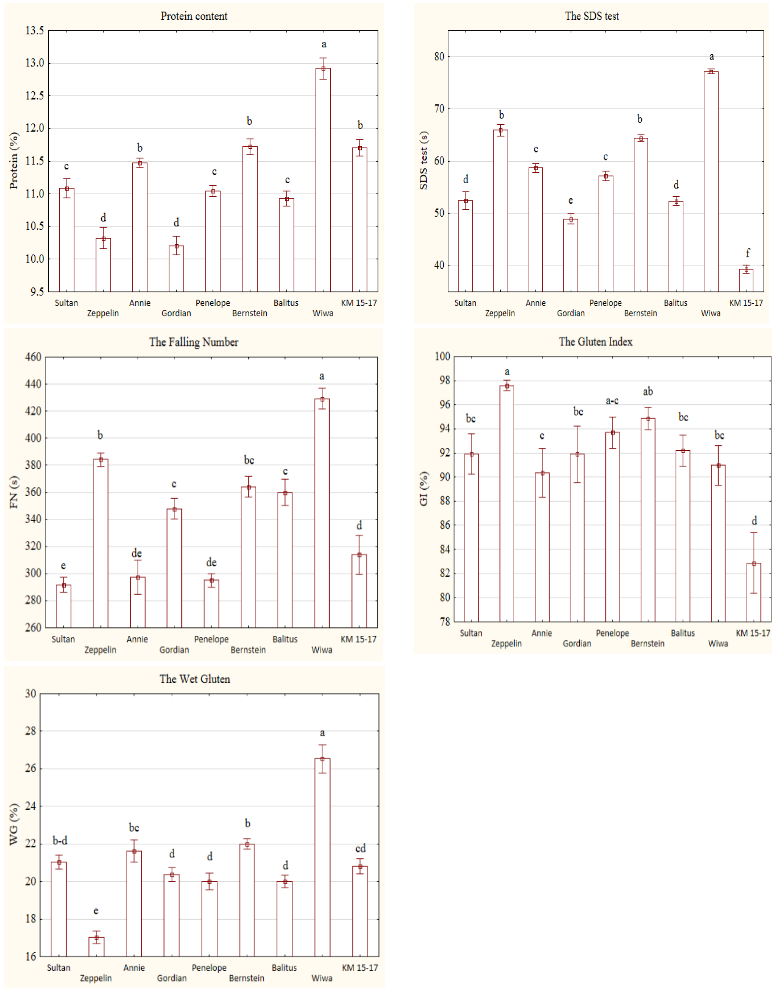
Results from Table 3, and Figure 2 illustrated that the amount of protein content went down during three years from 11.80 % to 10.78 %, decreasing by 1.02 %. The significant differences in statistic were found for this index between years, locations, and

Table 3: Means ± standard error (SE) and ANOVA F-value for the effects of harvest year, location, and wheat species on protein content, SDS test, falling number, gluten index, and wet gluten

	Protein (%)	SDS test (ml)	FN (s)	GI (%)	WG (%)
Harvest year					
2017	11.80 ± 0.11a	57.57 ± 1.17ns	321.37 ± 6.26b	86.91± 1.42c	22.72 ± 0.36a
2018	11.21± 0.10b	57.29 ± 1.37ns	321.30 ± 6.86b	91.81± 0.76b	20.91± 0.37b
2019	10.78 ± 0.11c	57.29 ± 1.48ns	384.98 ± 6.02a	96.72 ± 0.35a	19.52 ± 0.28c
Location					
ZV	11.09 ± 0.09b	57.24 ± 1.03ns	338.00 ± 5.54b	95.82 ± 0.31a	20.41± 0.26b
CB	11.44 ± 0.09a	57.53 ± 1.16ns	347.11 ± 6.32a	87.81± 1.05b	21.68 ± 0.33a
ANOVA					
Main effects					
Harvest year (Y)	114.49 **	0.31 (ns)	139.7 **	86.28 **	113.82 **
Location (L)	40.51 **	0.72 (ns)	135.2 **	172.57 **	53.97 **
Species (S)	98.33 **	468.64 **	112.6 **	19.33 **	92.34 **
Interactions					
Y × L	1.51 (ns)	85.22 **	34.3 **	45.13 **	6.75 **
Y × S	2.45 **	10.63 **	9.1 **	1.22 (ns)	4.69 **
L × S	2.96 **	21.19 **	7.2 **	7.48 **	1.68 (ns)
Y × L × S	1.24 (ns)	6.20 **	7.7 **	2.10 *	4.03 **

Mean values associated with different lowercase letters are significant different within each column analyzed by one-way ANOVA, Turkey's test, *p value* < 0.05. ns: Not significant. *: *p value* < 0.05. **: *p value* < 0.001 CB: Ceske Budejovice. ZV: Zvikov.

Figure 2: Contents of protein, SDS test, the falling number, gluten index, and wet gluten



varieties. Analysis of variance of protein content (harvest year, $F = 114.49$, $p < 0.001$; location, $F = 40.51$, $p < 0.001$, species, $F = 98.33$, $p < 0.001$) indicated that obviously, harvested year and species were more influenced than location. The interaction of two factors (year × location, location × species) were significant with p value < 0.001, while the interaction of three factors (year × location × species) and the interaction between year and location were insignificant. Compared to all cultivars, Wiwa had the highest amount of protein content with 12.92 ± 0.16 %, followed by Bernstein, KM 15 - 17, and Annie with 11.72 ± 0.12, 11.70 ± 0.12, and 11.47 ± 0.07, respectively. The lowest protein content was found in the flour of Zeppelin with 10.32 ± 0.16 %. These results are out of ranging of protein content (12.9 - 19.9 %) in the research of Shewry *et al.*, and Tran *et al.* exception Wiwa cultivar (Shewry *et al.*, 2013; Tran *et al.*, 2020).

The SDS Test

Sodium dodecyl sulphate (SDS) test was determined in flour samples according to the method of Axford *et al.* This method quoted the link with superior baking quality and stronger gluten (Axford *et al.*, 1978). The mean values of SDS test were not significant difference among years and locations. The data from Table 3 indicated that species had more effect on SDS test parameter with $F = 468.64$, $p < 0.001$, while locations and harvest year was not an effect on this index. In addition, the interaction between two factors and three factors were found with p value < 0.001. The SDS test of all varieties ranged from 39.30 ± 0.78 ml to 77.17 ± 0.51 ml. The highest sedimentation volume was observed in the Wiwa variety whilst the lowest one belonged to KM 15 - 17 variety. The second highest SDS test included Zeppelin and Bernstein with 65.94 ± 1.13 ml, and 64.38 ± 0.62 ml, respectively. In comparison to other results, the sedimentation volume in our study is higher than the results of Dhaka and Khatkar (47.10 ml), apart from KM 15 - 17 variety; and lower than the ones of Oelofse *et al.* (63.64 ml), exception in wheat cultivar Wiwa, Zeppelin, and Bernstein. (Dhaka and Khatkar, 2013; Oelofse et al., 2010).

The Falling Number

The impact of years, locations, and varieties as well as the interaction were found in the falling number.

What is more, the falling number mean values were almost similar between 2017 and 2018, but it was significant difference from the data of 2019 with approximately 63.65 second less. The figures also show that the falling number in Zvikov was longer 9,11 s than in Ceske Budejovice. Regarding to the interactions (Table 3), the influence of environment and variety on the mean values of the falling number was highly statistically significant with p value < 0.001. Compared to all cultivars, Wiwa had the highest falling number with 429.16 ± 7.49 s, followed by Zeppelin (384.16 ± 4.95 s) and Bernstein (364.08 ± 7.69 s). The lowest falling number group was Annie, Penelope, and Sultan with 297.29 ± 12.67 s, 295.00 ± 5.09 s, and 291.75 ± 5.41 s, respectively. To evaluate the baking properties and the enzymatic activity of wheat flour, the AACC 56 - 81 B and ICC Standard 107/1 were used (AACC 56 - 81 B, 2000b; ICC - Standard No. 107/1, 1995). Thus, the varieties having falling number are less than 300 s such as Sultan, Gordian, and Annie have the optimal activity as well as very good crumb of bread. The remainder varieties have the low enzymatic activity and are dry crumb of bread and reducing loaf volume.

The Gluten Index

From the Table 3, and Figure 2, an increasing tendency of GI was observed via the different year study from 86.91 % to 96.72 %. Thus, GI increased by 9.81 % for three years. The figures pointed out that the impact of location was higher than harvest year and species, but the interaction between year and species was not found. Three years analysis of nine wheat genotypes confirmed the statistically significant difference. The group having the highest GI was Zeppelin (97.59 ± 0.43 %), Bernstein (94.87 ± 0.91 %), and Penelope (93.68 ± 1.32 %). Conversely, KM 15 - 17 had the lowest GI with 82.86 ± 2.50 %. According to Cubadda *et al.*, gluten index was classified as three groups: Less than 30 % belonging to the weak flours; from 30 to 80 % belonging to the normal flour; greater than 80 % belonging to the strong flour (Cubadda *et al.*, 1992). In comparison with the results of Cubadda *et al.*, the varieties in our experiments are higher 80 % gluten index, therefore, they are categorized the strong flour.

The Wet Gluten

Unlike with the GI trend, wet gluten declined gradually for three years by 3.2 % and was influenced by harvest year with $F = 113.82$, $p < 0.001$. The interaction of two factors and three factors were found with p value < 0.001, apart from the interaction between location and year. However, the wet gluten had the same tendency with protein content. The highest wet gluten was observed in the Wiwa cultivar (26.53 ± 0.76 %) in comparison to other wheat cultivars. In contrast, KM 15 - 17 and Zeppelin had the lowest one with 20.80 ± 0.39 % and 17.02 ± 0.32 %, respectively.

The Rheological Evaluation of Different Wheat Flour

The water absorption of all wheats varied in a relatively narrow, ranging from 55.24 to 62.05 % and were significant difference. In comparison to all cultivar, Annie had the highest mean values of water absorption, whereas Sultan had the lowest one with 55.24 %. According to Mixolab manual, a wheat flour sample is considered strong when its value presented water absorption over 55 $g.100\ g^{-1}$ or 55 %. To compare with the results of Banfalvi *et al.* (Bánfalvi *et al.*, 2020) with water absorption varying from 57.5 to 64.1 %, our results are a little lower, but they also are over 55 % water absorption, an indicator for good baking quality.

Table 4: Data obtained from Mixolab parameters for the rheological evaluation of nine wheat varieties

Genotype	Water absorption (%)	Time of C1 (min)	Torque C1 (Nm)	Alfa	Amplitude	Stability (min)
Sultan	55.24 ± 0.13h	2.78 ± 0.12a-c	1.11 ± 0.00(ns)	-0.08 ± 0.00ab	0.08 ± 0.00a	6.74 ± 0.30e
Zeppelin	59.23 ± 0.13d	2.38 ± 0.08cd	1.10 ± 0.00(ns)	-0.08 ± 0.00ab	0.08 ± 0.00a	7.60 ± 0.40cd
Annie	62.05 ± 0.25a	2.96 ± 0.09ab	1.09 ± 0.00(ns)	-0.07 ± 0.00a	0.06 ± 0.00b	6.99 ± 0.27de
Gordian	56.90 ± 0.16f	2.35 ± 0.08cd	1.10 ± 0.00(ns)	-0.07 ± 0.00a	0.08 ± 0.00a	6.45 ± 0.27e
Penelope	58.07 ± 0.22e	2.59 ± 0.10bc	1.09 ± 0.00(ns)	-0.09 ± 0.00cd	0.08 ± 0.00a	8.47 ± 0.25ab
Bernstein	58.36 ± 0.11e	2.60 ± 0.15c	1.09 ± 0.00(ns)	-0.09 ± 0.00cd	0.09 ± 0.00a	8.36 ± 0.25a-c
Balitus	55.83 ± 0.11g	2.74 ± 0.22a-c	1.09 ± 0.00(ns)	-0.08 ± 0.00bc	0.08 ± 0.00a	7.68 ± 0.28b-d
Wiwa	59.76 ± 0.18c	3.18 ± 0.18a	1.10 ± 0.00(ns)	-0.09 ± 0.00d	0.09 ± 0.00a	8.76 ± 0.13a
KM 15-17	60.49 ± 0.14b	1.89 ± 0.10d	1.09 ± 0.00(ns)	-0.08 ± 0.00b	0.08 ± 0.00a	6.34 ± 0.24e

Mean values associated with different lowercase letters are significant different within each column analyzed by one-way ANOVA, Turkey's test, p value < 0.05. ns: Not significant.

Table 5: Data obtained from Mixolab parameters for the rheological evaluation of nine wheat varieties

Genotype	Torque C2 (Nm)	Beta	Torque C3 (Nm)	Gamma	Torque C4 (Nm)	Torque C5 (Nm)
Sultan	0.44 ± 0.01cd	0.53 ± 0.03b-d	1.76 ± 0.04a-c	-0.09 ± 0.02b	1.39 ± 0.05b	2.48 ± 0.05b
Zeppelin	0.45 ± 0.01c	0.44 ± 0.01e	1.73 ± 0.01b-d	-0.04 ± 0.01a	1.50 ± 0.02ab	2.30 ± 0.05c
Annie	0.42 ± 0.01d	0.40 ± 0.01e	1.50 ± 0.03f	-0.07 ± 0.00b	0.94 ± 0.05d	1.57 ± 0.08f
Gordian	0.52 ± 0.01a	0.47 ± 0.05c-e	1.60 ± 0.08e	-0.06 ± 0.01ab	1.46 ± 0.02ab	2.60 ± 0.04ab
Penelope	0.44 ± 0.01cd	0.46 ± 0.02de	1.69 ± 0.03cd	-0.06 ± 0.01ab	1.24 ± 0.06c	2.10 ± 0.09d
Bernstein	0.48 ± 0.01b	0.63 ± 0.02a	1.81 ± 0.01ab	-0.07 ± 0.01ab	1.48 ± 0.02ab	2.60 ± 0.05ab
Balitus	0.44 ± 0.01cd	0.60 ± 0.02ab	1.83 ± 0.02a	-0.07 ± 0.01b	1.53 ± 0.04a	2.70 ± 0.07a
Wiwa	0.48 ± 0.01b	0.56 ± 0.02ab	1.82 ± 0.01a	-0.06 ± 0.01ab	1.55 ± 0.02a	2.61 ± 0.04a
KM 15-17	0.39 ± 0.00e	0.55 ± 0.03a-c	1.67 ± 0.04de	-0.07 ± 0.01ab	1.16 ± 0.08c	1.81 ± 0.11e

Mean values associated with different lowercase letters are significant different within each column analyzed by one-way ANOVA, Turkey’s test, *p value* < 0.05. ns: Not significant.

In the first stage of Mixolab analysis, the dough development time (C1 time) is an essential index, which is known as the dough development or the gluten development time. Longer C1 time was observed for three varieties namely Wiwa, Annie, Sultan, and Balitus with mean value respectively being 3.18 s, 2.96 s, 2.78 s, and 2.74 s. Similarly, the stability plays an important role in the first stage. This index reflects the resistance of dough against intensive mixing. From the Table 4 shows that Wiwa, Penelope, and Bernstein cultivar belonged the group having the longest stability with 8.76 minutes, 8.47 minutes, and 8.36 minutes, respectively. In contrast, Annie (6.99 minutes), Sultan (6.74 minutes), Gordian (6.45 minutes), and KM 15 - 17 (6.34 minutes) had the shortest stability. As expected, torque C1 was insignificant difference among varieties and varied in a small narrow, which ranged from 1.09 to 1.11 Nm. In term of amplitude, only Annie variety was statistically significant difference as compared with other varieties and had the lowest number (0.06). In general, the dough development time ranges from 0.99 to 7.36 minutes. Our results were categorized this ranging. In comparison with the results of Banfalvi *et al.*, C1 time in our study was shorten than the mean value of Banfalvi *et al.* (4.71 minutes), however, the stability of some varieties in our study were higher 8.12 minutes. The previous our study showed that the C1 time of Vanek and SW Kardili are nearly double longer time than all varieties in this study. The stability is also higher than these ones. As reported by Lundh and Macritchie (Lundh and Macritchie, 1989), the difference in proportion of glutenin results in the differences of dough development time. The greater proportion of gluten wheat flour gets, the better baking performance and stronger dough properties wheat flour has. The results of Moreira *et al.*, was confirmed the cite above and pointed that longer dough stability are associated with strong flour (Moreira *et al.*, 2011). Thus, a stronger flour having the longer dough development time (≥ 3 minutes) longer dough stability (≥ 4 minutes) was suitable for Wiwa, Annie, Sultan and Balitus.

In the second stage where torque C2 and slope α were evaluated. Figures in Table 4 and 5 confirmed the differences among studied cultivars for torque C2 and slope α parameters. The highest value of torque C2 was recorded for Gordian with 0.52 Nm, followed by Bernstein and Wiwa with 0.48 Nm, vice versa was true for Sultan, Penelope, Balitus, and Annie, ranging from 0.44 to 0.42 Nm. The slope α implying the speed of the protein network attenuating varied from - 0.09 to - 0.07 and was significant difference. According to Lacko-Bartosova *et al.*, Banfalvi *et al.*, Svec and Hruskova, Schmiele *et al.*, Wiwart *et al.*, and Dhaka *et al.*, strong wheat flour has the C2 value higher than 0.4 Nm. If this value ranges from 0.5 to 0.6 Nm, it refers to good quality protein, the higher ability resistance of gluten to heating, and stronger gluten network (Bánfalvi *et al.*, 2020; M. Lacko-Bartošová *et al.*, 2019; Schmiele *et al.*, 2017; Švec and Hrušková, 2015; Dhaka *et al.*, 2014; Wiwart *et al.*, 2017). Like that, accompanying with the dough development time, and the dough stability, the torque C2 is also related to the properties of gluten. The results of the value C2 torque analyzed in our study was higher 0.4 Nm (exception KM 15 - 17), especially, Gordian cultivar had the value higher than 0.5 Nm. The explanation for KM 15 - 17 was due to the fact that it had the lowest gluten index as compared with other varieties.

The third stage, characterized by torque C3 and slope β parameters, has the heating until reaching 70 ^{0}C. Although dough remained under constant mixing, the process of protein denaturation and starch gelatinization stopped (Schmiele *et al.*, 2017). Results from Table 5 confirmed that torque C3 ranged from 1.50 to 1.83 Nm. Maximum torque C3 was recorded for Batilus, Wiwa, Bernstein, and Sultan with 1.83 Nm, 1.82. Nm, 1.81 Nm, and 1.76 Nm, respectively. Conversely, minimum torque C3 was recorded for Annie with 1.50 Nm. These results are similar to with our previous study (Tran *et al.*, 2020), are lower than the results of Wiwart *et al.*, but are higher than the ones of Banfalvi *et al.* (Bánfalvi *et al.*, 2020; Wiwart *et al.*, 2017). Regarding to the slope β parameter, an indicator for the starch gelatinization speed, the mean values of Bernstein, Balitus, Wiwa, and KM 15 - 17 were found to be significantly higher than other varieties and higher the findings of Wiwart *et al.* (0.57). This means that they had faster gelatinization process.

In the fourth stage, the parameters torque C4 and slope γ were assessed. The results of the assessment of different cultivar in Table 5 indicate that the torque C4 fluctuated from 0.94 to 1.55 Nm. A statistically significant difference was witnessed for all varieties with the highest value belonging to Wiwa (1.55 Nm), Balitus (1.53 Nm), Zeppelin (1.50 Nm), Bernstein (1.48 Nm), and Gordian (1.46 Nm). In contrast, the minimum value was recorded for Annie with 0.94 Nm. In comparison with the findings other authors, our results were lower, especially for Annie variety. This implied that the resistance of starch against the enzymatic hydrolysis by amylose and the hot gel stability of our sample were lower than the counterpart results. The slope γ displays the speed of enzymatic degradation of starch and the heating stability of starch gel. Unlike the slope α and β, the slope γ was more variation from - 0.09 to - 0.04. However, only Zeppelin was significant difference with Balitus, Annie, and Sultan, the remainder varieties was similar when compared together. The results of Wiwart *et al.* ranged from - 0.06 to - 0.10 was a little lower than our results.

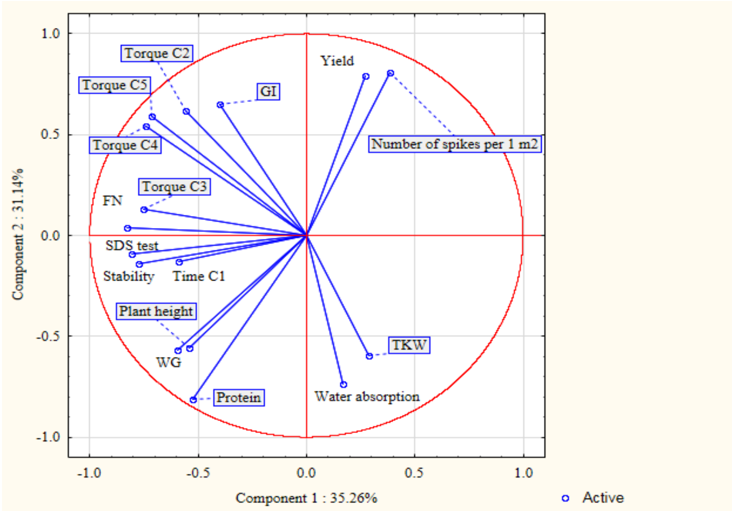
In the final stage, the values of torque C5 varied from 1.57 to 2.70 Nm. Significantly, the higher value of torque C5 was noted in reference to Balitus (2.70 Nm), Wiwa (2.61 Nm), Gordian (2.60 Nm), and Bernstein

(2.60 Nm), whereas Annie had the lowest value of torque C5 with 1.57 Nm. These results, higher than our previous study and higher the results of standard sample flour reported by Svec and Hruskova (Švec and Hrušková, 2015), indicated a high level of starch retrogradation.

The Correlation among Agronomical Traits, Quality Parameters and Mixolab Parameters and Statistics Analyzed by Principal Component Analysis

From the Figure 3, strong correlations were seen among the falling number, SDS test, the stability, time C1, and torque C3; among Protein, wet gluten, and plant height; among gluten index, torque C2, torque C5, and torque C4; between yield and the number of spikes per m^2. What is more, SDS test was found closely with the stability, time C1, and torque C3, and gluten index was positive correlation with torque C2, which are in agreement with the results of Dhaka *et al.* and Collar *et al.* reported the correlations among SDS test, time C1, the stability and torque C3 and between gluten index with torque C2 (Collar *et al.*, 2007; Dhaka *et al.*, 2014).

Figure 3: The projection of study variables based on correlations

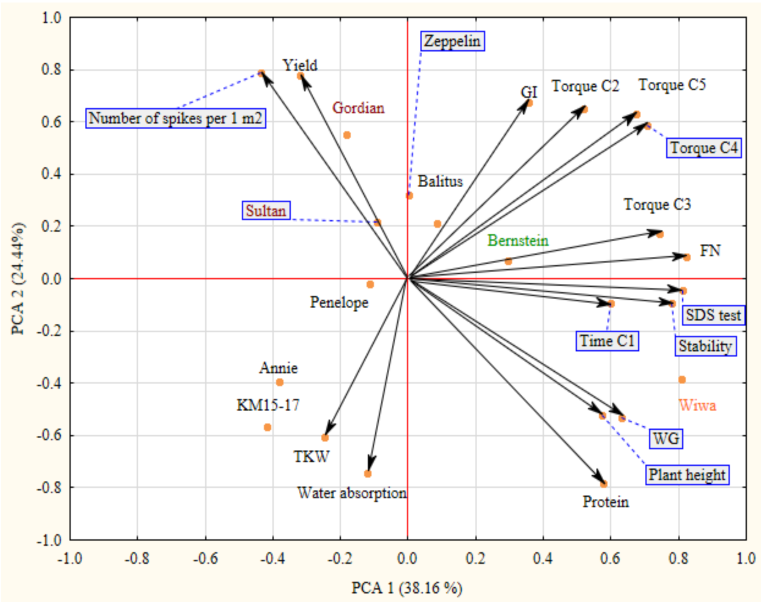


Also, the figures showed that the yield variable was strongly negative correlation with protein, this implies higher yield are relation to the lower protein content as the results reported by Jablonskyte-Rasce *et al.* (Jablonskytė-Raščė *et al.*, 2013). Similar to the results of Spanic *et al.*, our results indicated the strong correlation between protein and wet gluten, but no correlation was seen among protein, wet gluten and gluten index (Spanic *et al.*, 2021). Regarding to agronomic traits, plant height and TKW had a negative correlation with the yield, while the number of spikes per m^2 showed an opposite trend. This indicates that the number of spikes per m^2 in our experiments was a decisive factor to the yield, which is in concordance with Mason *et al.* and Mayer *et al.*, who reported that the number of spikes per m^2 was the important factor of yield component responsible for the wheat yield in organic farming (Mason *et al.*, 2007; Mayer *et al.*, 2015).

The Identification of Varieties Association with High Yield and Good Baking Quality

Obviously, the Sultan and Gordian variety were located near the loading of yield. This mean that they have the highest yield than other varieties. In contrast, the position of Wiwa cultivar was in close proximity to the protein, WG, and the quality parameters such as time C1 the stability, SDS test, the falling number, and torque C3. Thus, Wiwa cultivar was seen a potential cultivar for good baking performance. For KM 15 - 17, Annie, and Penelope, an opposite direction with the loading of quality parameters was observed in biplots because they had the lowest ones. In our study, a successful cultivar having both high yield and good baking performance is that Bernstein because it is situated in the middle of loading yield and loading quality traits in PCA 1.

Figure 4: Principal component analysis biplot based upon various quantitative and quality traits of nine wheat cultivars using mean value of two locations in three years



Conclusions

The Agronomical Parameters

- The results of analyses depict that the environment affected to the quantitative parameters for different years and locations study. In detail, the plant height, and the number spikes per m^2 were impacted by different years more than locations and species. The factors such as harvest year, location, and species are the same effect on TWK. Yield is strongly affected by location more than harvest year and species.

- The weather condition in 2018 - 2019 was favor with the vegetation and development phase of wheat with the precipitation steadily distribution during growing season and the temperature suitable for wheat growing in sensitive periods.

- The Sultan, Gordian, and Bernstein cultivar having the highest yield are selected for the potential high yield cultivar.

- There is a strong relationship between the number of spikes per m^2 and yield.

The Quality Parameters

- The effects of harvest year, location, and species on protein content, SDS test, the falling number, gluten index, and wet gluten are found. The harvest of different years is more effect on protein content and wet gluten than species and location. The gluten index is affected by location more than harvest year and location. SDS test is only impacted by species.

- All varieties are classified as strong flour with high SDS test and Gluten index, apart from KM 15 - 17.

- A strong correlation is observed between SDS test and falling number and between wet gluten and protein, fair correlation is true between SDS test and wet gluten.

- The best quality is detected for Wiwa cultivar, which is characterized the highest protein content. SDS test and wet gluten.

The Rheological Properties

- The water absorption of all wheats, ranging from 55.24 to 62.05 %, belongs to strong flour group.

- The best rheological behavior is found for Wiwa, Annie, Sultan and Balitus cultivar with the longer dough development time (≥ 3 minutes), longer dough stability (≥ 4 minutes), and higher C2 value (≥ 0.4 Nm).

- The high level of starch retrogradation is found in Balitus, Wiwa, Gordian, and Bernstein cultivar.

- A strong correlation is seen between the time C1 and the stability dough, and between torque C4 and torque C5. Fair strong is observed between GI and torque C2.

The Conclusions Based upon PCA

- Sultan and Gordian are the potential high yield cultivar.

- Wiwa is the good bread making cultivar.

- Bernstein is a successful cultivar having both high yield and good baking performance.

Recommendations

- Further research in different regions is necessary to assesses the adaptation of all varieties in this study.

- Further agronomical traits should research such as the number of grains per spike, the weight of grains per spike, the weed competitiveness, and the resistance to usual diseases to be able to take appropriate conclusion.

- To expand the growing area for Bernstein cultivar.

- Wiwa cultivar has the potential bread making, and Sultan and Gordian have the potential high yield that should use for the breeding process in organic farming in the near future.

References

1. AACC 38 - 12 A, 2000a. Approved Methods of the American Association of Cereal Chemists, 10th edn. St. Paul : American Association of Cereal Chemists.

2. AACC 56 - 61.02, 1999. Approved Methods of Analysis, 11th Edition - AACC Method 56 - 61.02. Sedimentation Test for Wheat [WWW Document]. URL http://methods.aaccnet.org/summaries/56 - 61 - 02.aspx (accessed 4.13.21).

3. AACC 56 - 81 B, 2000b. Approved Methods of The American Association of Cereal Chemists, 10th edn. St. Paul : American Association of Cereal Chemists.

4. Arterburn, M., Murphy, K., Jones, S.S., 2012. Wheat: Breeding for Organic Farming Systems, Bueren E. T. L. and Myers J. R. ed. Wiley-Blackwell. ISBN: 978-0-470-95858-2.

5. Axford, D., Mcdermott, E., Redman, D., 1978. Small-Scale Tests of Bread-Making Quality. Cereal Chemistry 18 - 20.

6. Bánfalvi, Á., Németh, R., Bagdi, A., Gergely, S., Rakszegi, M., Bedő, Z., Láng, L., Vida, G., Tömösközi, S., 2020. A Novel Approach to the Characterization of Old Wheat (*Triticum aestivum* L.) Varieties by Complex Rheological Analysis. Journal of the Science of Food and

Agriculture 100, 4409 - 4417. https://doi.org/10.1002/jsfa.10479.

7. Ceseviciene, J., Leistrumaite, A., Paplauskienė, V., 2009. Grain Yield and Quality of Winter Wheat Varieties in Organic Agriculture. Agronomy Research 7, 217 - 223. https://agronomy.emu.ee/vol07Spec1/p7sI12.pdf.

8. Collar, C., Bollain, C., Rosell, C.M., 2007. Rheological Behaviour of Formulated Bread Doughs During Mixing and Heating. Food Science and Technology International 99 - 107. https://journals.sagepub.com/doi/10.1177/1082013207078341.

9. Cox, W., Cherney, J., Sorrells, M., 2019. Organic Compared with Conventional Wheat Had Competitive Yields during the Early Years of Organic Production in the Northeast USA. Agronomy 9, 380. https://doi.org/10.3390/agronomy9070380.

10. Cubadda, R. (Molise U., Carcea, M., Pasqui, L.A., 1992. Suitability of the Gluten Index Method for Assessing Gluten Strength in Durum Wheat and Semolina. Cereal Foods World (USA).

11. Curna, V., 2016. Agronomic Performance and Quality Parameters. The Dissertation.

12. Dhaka, V., Gulia, N., Khatkar, B., 2014. Application of Mixolab to Assess the Bread Making Quality of Wheat Varieties. https://doi.org/10.4172/scientificreports.183.

13. Dhaka, V., Khatkar, B. s., 2013. Mixolab Thermomechanical Characteristics of Dough and Bread Making Quality of Indian Wheat Varieties. Quality Assurance and Safety of Crops & Foods 5, 311 - 323. https://doi.org/10.3920/QAS2012.0166.

14. Gevrek, M.N., Atasoy, G.D., 2012. Performance of Some Bread Wheat Genotypes under Organic and Conventional Production Systems. International Journal of Agriculture and Biology (Pakistan). https://www.researchgate.net/publication/285940073_Performance_of_some_Bread_Wheat_Genotypes_under_Organic_and_Conventional_Production_Systems.

15. ICC - Standard No. 107/1, 1995. Determination of the "Falling Number" According to Hagberg - as a Measure of the Degree of Alpha-Amylase Activity in Grain and Flour.

16. ICC - Standard No. 155, 1994. Determination of Wet Gluten Quantity and Quality (Gluten Index ac. to Perten) of Whole Wheat Meal and Wheat Flour (*Triticum aestivum*).

17. ICC - Standard No. 158, 1995. Gluten Index Method for Assessing Gluten Strength in Durum Wheat (*Triticum durum*).

18. ICC - Standard No. 173, 2006. Whole Meal and Flour from *T. aestivum* - Determination of Rheological Behavior as a Function of Mixing and Temperature Increase.

19. Jablonskytė-Raščė, D., Maikštėnienė, S., Mankevičienė, A., 2013. Evaluation of Productivity and Quality of Common Wheat (*Triticum aestivum* L.) and Spelt (*Triticum spelta* L.) in Relation to Nutrition Conditions. Zemdirbyste-Agriculture 100, 45 - 56. https://doi.org/10.13080/z-a.2013.100.007.

20. Jańczak-Pieniążek, M., Buczek, J., Kaszuba, J., Szpunar-Krok, E., Bobrecka-Jamro, D., Jaworska, G., 2020. A Comparative Assessment of the Baking Quality of Hybrid and Population Wheat Cultivars. Applied Sciences 10, 7104. https://doi.org/10.3390/app10207104.

21. Konvalina, P., Capouchova, I., Stehno, Z., Moudry, J. (Jr), Moudry, J., 2011a. Spike Productivity in Relation to Yield as Criterion for Emmer Wheat Breeding. Romanian Agricultural Research. URL https://orgprints.org/id/eprint/20760/ (accessed 4.15.21).

22. Konvalina, P., Stehno, Z., Capouchova, I., Moudry, J., 2011b. Wheat Growing and Quality in Organic

Farming, in: Nokkoul, R. (Ed.), Research in Organic Farming. InTech. https://doi.org/10.5772/29330.

23. Lacko-Bartošová, Magdaléna, Konvalina, P., Lacko-Bartošová, L., Štěrba, Z., 2019. Quality Evaluation of Emmer Wheat Genotypes Based on Rheological and Mixolab Parameters. Czech Journal of Food Sciences 37 (2019), 192 - 198. https://doi.org/10.17221/101/2018-CJFS.

24. Lundh, G., Macritchie, F., 1989. Size Exclusion HPLC Characterisation of Gluten Protein Fractions Varying in Breadmaking Potential. Journal of Cereal Science 10, 247 - 253. https://doi.org/10.1016/S0733-5210(89)80054-2.

25. Mason, H.E., Navabi, A., Frick, B.L., O'Donovan, J.T., Spaner, D.M., 2007. The Weed-Competitive Ability of Canada Western Red Spring Wheat Cultivars Grown under Organic Management. Crop Science 47, 1167 - 1176. https://doi.org/10.2135/cropsci2006.09.0566.

26. Mayer, J., Gunst, L., Mäder, P., Samson, M.-F., Carcea, M., Narducci, V., Thomsen, I.K., Dubois, D., 2015. "Productivity, Quality and Sustainability of Winter Wheat under Long-term Conventional and Organic Management in Switzerland." European Journal of Agronomy 65, 27 - 39. https://doi.org/10.1016/j.eja.2015.01.002.

27. Moreira, R., Chenlo, F., Torres, M.D., 2011. Effect of Sodium Chloride, Sucrose and Chestnut Starch on Rheological Properties of Chestnut Flour Doughs. Food Hydrocolloids 25, 1041 - 1050. https://doi.org/10.1016/j.foodhyd.2010.09.025.

28. Oelofse, R.M., Labuschagne, M.T., Van Deventer, C.S., 2010. Influencing Factors of Sodium Dodecyl Sulfate Sedimentation in Bread Wheat. Journal of Cereal Science 52, 96 - 99. https://doi.org/10.1016/j.jcs.2010.03.010.

29. Schmiele, M., Ferrari Felisberto, M.H., Pedrosa Silva Clerici, M.T., Chang, Y.K., 2017. MixolabTM for Rheological Evaluation of Wheat Flour Partially Replaced by Soy Protein Hydrolysate and Fructooligosaccharides for Bread Production. LWT - Food Science and Technology, SLACA 2015: “Food Science for Quality of Life and Health Ageing” 76, 259 - 269. https://doi.org/10.1016/j.lwt.2016.07.014.

30. Shewry, P.R., Hawkesford, M.J., Piironen, V., Lampi, A.-M., Gebruers, K., Boros, D., Andersson, A.A.M., Åman, P., Rakszegi, M., Bedo, Z., Ward, J.L., 2013. Natural Variation in Grain Composition of Wheat and Related Cereals. Journal of Agricultural and Food Chemistry 61, 8295 - 8303. https://doi.org/10.1021/jf3054092.

31. Spanic, V., Cosic, J., Zdunic, Z., Drezner, G., 2021. Characterization of Agronomical and Quality Traits of Winter Wheat (*Triticum aestivum* L.) for Fusarium Head Blight Pressure in Different Environments. Agronomy 11, 213. https://doi.org/10.3390/agronomy11020213.

32. Švec, I., Hrušková, M., 2015. The Mixolab Parameters of Composite Wheat/hemp Flour and Their Relation to Quality Features. LWT - Food Science and Technology 60, 623 - 629. https://doi.org/10.1016/j.lwt.2014.07.034.

33. Tran, K.D., Konvalina, P., Capouchova, I., Janovska, D., Lacko-Bartosova, M., Kopecky, M., Tran, P.X.T., 2020. Comparative Study on Protein Quality and Rheological Behavior of Different Wheat Species. Agronomy 10, 1763. https://doi.org/10.3390/agronomy10111763.

34. Wiwart, M., Szafrańska, A., Wachowska, U., Suchowilska, E., 2017. Quality Parameters and Rheological Dough Properties of 15 Spelt (*Triticum spelta* L.) Varieties Cultivated Today. Cereal Chemistry 94, 1037 - 1044. https://doi.org/10.1094/CCHEM-05-17-0097-R.