NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 41, 2024
www.incda-fundulea.ro; doi.org/10.59665/rar4117 First Online: January, 2024. DII 2067-5720 RAR 2024-65

Baking Quality of Organically Grown European Winter Wheat Germplasm in the South-East of Romania

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ABSTRACT

Baking quality of organic winter wheat remains a significant challenge, primarily due to the usually lower grain protein concentration realized in organic agriculture. This study examined eighty-four winter wheat genotypes from Europe under organic conditions in the south-east of Romania, during two contrasting seasons. Various quality traits, i.e., grain protein content, bread volume, dough strength, breakdown and extensibility were analyzed. All examined traits exhibited significant differences among cultivars. Molecular assays, utilizing markers for *Glu-A1*, *Glu-D1*, *Glu-B3g* and *NAM-A1* loci revealed genetic diversity within the germplasm. The study highlighted sixteen genotypes with bread volume statistically significant different from the average trial. In the organic system the *Glu-A1x2 allele had positive effects on bread volume, water absorption, dough strength and extensibility. At *Glu-D1*, the alleles for Dx5 + Dy10 were detected in over 85% cultivars and showed positive effects on dough development time and extensibility. Another locus with positive effect on baking quality was *NAM-A1*. In this study the haplotype *NAM-A1c* had the highest frequency (51%), followed by *NAM-A1d* (38%) and *NAM-A1a* (11%). Both *NAM-A1a* and *NAM-A1c* haplotypes positively affected bread volume, water absorption, dough strength and extensibility. The *Glu-B3g* allele had a positive effect on development time. However, these genes could not explain the whole variation of quality parameters, as some of the best cultivars had unfavorable alleles while other cultivars carrying positive alleles had low quality. Obviously, other factors strongly influenced the quality parameters in organic agriculture, and further research is needed to understand their nature. Our results suggest the potential for achieving improved breadmaking quality, under organic conditions, by exploring genetic possibilities. However, combining suitable breadmaking quality with high yield will remain a challenge.**

Keywords: winter wheat, organic agriculture, baking quality, *NAM-A1*.

INTRODUCTION

Wheat and consecutively flour quality depends on a range of factors, as wheat variety, crop year, agrotechnical treatment and final processing. Bread quality is affected by both flour properties and baking process used (Švec and Hrušková, 2010).

The unique rheological properties of bread wheat dough and the breadmaking quality of its flour are the main factors responsible for the global distribution and utilization of wheat (Takač et al., 2021). Baking quality is the flour's capacity to ensure a high-volume bread, elastic, with a uniform pore distribution and suitable dough behavior in the process of mixing. It is influenced significantly by grain protein content (GPC), polymer structure of the protein (gluten quality) and grain hardness (Neacşu et al., 2010). Protein composition and content as the main determinants of wheat bread making quality are affected by genetics, environmental conditions, and crop management (Pepo et al., 2005; Drezner et al., 2007; Marinciu, 2007; Horvat et al., 2009; Neacşu et al., 2010).

Organic farming is a system using a limited quantity of chemical fertilizers (especially nitrogen). The ability to absorb nitrogen in early spring is a critical issue in growing winter cereals in an organic farming system (Köpke, 2005; Konvalina et al., 2011). To obtain wheat with proper baking quality under organic condition is a challenge for farmers because it is very difficult to obtain grains with high protein concentrations under the low and variable availability of nitrogen during the grain-filling phase,

Received 28 November 2023; accepted 17 January 2024.

common in organic farming. Low protein content in wheat grains thus needs to be compensated by a high proportion of high-quality protein. Organic farming needs cultivars with genes encoding for optimal levels of glutenins and gliadins, a maximum ability for nitrogen uptake, a large storage capacity of nitrogen in the biomass, an adequate balance between vegetative and reproductive growth, a high nitrogen translocation efficiency for the vegetative parts into the grains during grain filling and an efficient conversion of nitrogen into high-quality proteins (Osman et al., 2012).

Several researchers found that modern varieties of wheat were more efficient, they absorbed more nitrogen and were able to use it more efficiently than the older ones (Muurinen et al., 2006; Konvalina et al., 2011).

On the other hand, other researchers considered that modern bread wheat varieties developed for high input conventional production systems may lack traits desired by organic farmers, including competitiveness against weeds, disease resistance, and nutrient uptake efficiency from organic fertilizer inputs (Wilkinson et al., 2023). They highlighted that cultivar comparisons/trials carried out under conventional high-input agronomic practices do not accurately predict the performance and ranking of varieties in organic production, even when carried out in similar pedoclimatic environments (Wilkinson et al., 2023).

Rheological measurements have been used to give indication of the probable baking quality of dough.

High-molecular-weight glutenins (HMW) are encoded by the *Glu-1* loci on the long arms of chromosomes 1A, 1B and 1D, and these loci are designated *Glu-A1*, *Glu-B1* and *Glu-D1*, respectively. Low-molecular-weight glutenins (LMW) encoded by a multigene family located at the *Glu-A3*, *Glu-B3* and *Glu-D3* loci, on the short arms of chromosomes 1A, 1B, and 1D (Liu et al., 2010; Dreisigacker et al., 2020). For the *Glu-A1* locus, both the Ax1 and Ax2* subunits have positive effects on bread making quality and the null has a low-quality score. The *Glu-D1* locus has the largest effect on bread making quality. The combination of *Dx5 + Dy10* is associated with strong dough and good bread making quality (Payne et al., 1981). All previous studies agreed that both the HMW glutenins and LMW glutenins polymorphisms influence dough and end-use quality (Liu et al., 2010; Ram et al., 2015; Dreisigacker et al., 2020; Guzman et al., 2022).

The wheat (*Triticum aestivum* L.) has five *NAM* genes ("No Apical Meristem") three paralogs (on chromosomes 2A, 2B and 2D) and two homeologs (on chromosomes 6A and 6D) of which *NAM-A1* (6A) has a similar function to *NAM-B1* (*Gpc-B1 - Triticum turgidum* L. subsp. *dicoccoides*), with beneficial effects on the nutritional quality of cereals and on baking properties (Cormier et al., 2015). The *NAM-A1* gene has four haplotypes *NAM-A1a*, *NAM-A1b*, *NAM-A1c* and *NAM-A1d*.

Cormier et al. (2015) hypothesized that NAM-A1a could be a functional variant of the NAM-A1 gene. Later, the study on Australian cultivars sowed that *NAM-A1a* was associated with a short to moderate grain-filling phase, the alleles *c* and *d* were related to moderate to long grain-filling phase (Alhabbar et al., 2018).

The use of molecular tools for detection of HMW glutenins, LMW glutenins and *NAM-A1* alleles allow the proliferation of studies focused on analyzing of their effect on protein content and end-use quality in organic system.

The aim of this paper was to present results on the baking quality (protein concentration and rheological parameters) of a set of winter wheat cultivars grown organically, including the genetic profiles for *Glu-A1*, *Glu-D1*, *Glu-B3g* and *NAM-A1* loci to highlight the possibility of achieving better baking quality under these conditions.

MATERIAL AND METHODS

Eighty-four winter wheat cultivars originating from Romania (20 cultivars), Hungary (17 cultivars), Slovakia (19 cultivars), Slovenia (9 cultivars), Austria (6 cultivars), Serbia (13 cultivars), including old and new ones, were evaluated under organic conditions, at NARDI Fundulea (44°30`N latitude and 24°10`E longitude), in two replicates, randomized complete block design, during two seasons 2020-2021 and 2021-2022. The experimental plots had a harvestable area of five m^2. The preceding crop was soybean.

The weather conditions were contrasting, 2020-2021 was normal, but with uneven rainfall during the growing season, with a higher amount recorded during grain the grain-filling period. In contrast, 2021-2022 was dry (the drought was installed from August 2021, causing difficulties in the soil preparation, and continued throughout vegetation period). In both seasons, compost (organic fertilizer) at a rate of 450 kg/ha (4-3-3 NPK; BIO-FER NATUR) was applied in the autumn of 2021 and an organic fertilizer, Naturamin (250 g/ha) was used in the spring.

Protein content was analyzed using the Infratec 1241 (Foss, Hillerød, Denmark) grain analyzer. Rheological parameters were assessed using the Reomixer device (Bohlin Reologi AB, Lund, Sweden), which used ten grams flour, in accordance with the manufacturer's instructions. The Reomixer device measures torque by detecting the deflection of a lever arm constrained by a pair of stiff springs, using a non-contacting sensor. The software provided by the manufacturing company allows for determining thirteen mixing parameters describing specific characteristics of the mixing curve, plus three integrating (integrated height to peak - IHTP, area below and area within the mixing curve) and one calculated parameter, the estimated bread volume (BV). Neacşu et al. (2009) found that most information contained in this large number of mixing parameters can be condensed into five parameters, which describe the basic rheological aspects of dough development and are most suitable for breeding purposes: initial slope ("initslope") describing the water absorption phase; development time, or time to peak ("peaktime"), indicating the mixing requirements of the dough; peak height ("peakheight") reflecting dough strength or elasticity; dough breakdown ("breakdown"), describing dough stability or tolerance to over-mixing; and final width ("endwidth"), primarily representing dough extensibility. In our study we chose to analyze these five rheological parameters as mentioned above. The molecular analysis, for the *Glu-A1*, *Glu-D1*, *Glu-B3g* and *NAM-A1* loci followed the protocols outlined by Ciucă et al. (2023).

A linear model combined across genotypes, years and their interactions was performed for all parameters using the ANOVA procedure. Additionally, average values and the least significant difference (LSD) for each quality trait were calculated by averaging across years and genotypes. Linear regression was utilized to determine the correlation between grain yield and grain protein content, as well as between yield and estimated bread volume. Deviations from regression estimated bread volume (dependent variable) and grain yield (independent variable) were calculated for each cultivar.

Pearson's correlation coefficients between all quality parameters were computed using the "CORREL" function in Excel, included in the Microsoft 365 package.

RESULTS AND DISCUSSION

The baking industry requires flours with well-defined quality characteristics, including protein content, and rheological properties.

It is known that "loaf volume is a function of both the quantity and quality of flour proteins", and that "loaf volume increases with the rising protein content within a cultivar" (Finney and Barmore, 1948; Finney et al., 1987; Uthayakumaran et al., 1999; Kuhn et al., 2016; Marinciu et al., 2016).

ANOVA was calculated for select rheological parameters and grain protein percent. All the assessed quality parameters were significantly influenced by genotype, while the year strongly impacted the dough strength or elasticity ("peakheight"), dough stability ("breakdown"), dough extensibility ("endwidth") and estimated bread volume. The mixing requirements of the dough ("peaktime") and water absorption phase ("initslope") were not influenced by year. The interaction between genotype x year significantly influenced all analyzed quality parameters, except for protein percent and dough stability ("breakdown") (Table 1).

Table 1. ANOVA for analyzed quality parameters

Quality parameters	Source of Variation	F values	LSD 5%
Protein content	Variety	4.57**	1.28
	Year	73.06***	
	Interaction	0.85^{ns}	
Water absorption phase ("initslope")	Variety	8.61***	1.08
	Years	1.17^{ns}	
	Interaction	1.56*	
Mixing requirements of the dough ("peaktime")	Variety	4.87**	2.63
	Years	3.92^{ns}	
	Interaction	1.50*	
Dough strength ("peakheight")	Variety	15.72***	0.56
	Years	48.79***	
	Interaction	2.18*	
Dough stability ("breakdown")	Variety	4.34*	0.9
	Years	60.05***	
	Interaction	1.30^{ns}	
Dough extensibility ("endwidth")	Variety	3.08*	0.54
	Years	173.59***	
	Interaction	2.07*	
Estimated bread volume	Variety	11**	98.63
	Year	52***	
	Interaction	2*	

**** = significant at P<0.1%; ** = significant at P<1%; * = significant at P<5%; ^{ns} = insignificant for P<5%.*

The recorded variation for grain protein percent ranged from 8.0% (in the *Mv Káplár* cultivar) and 12.5% (in the *Alessio* cultivar) during the 2020-2021 season, and from 8.3% (in the *FDL Miranda* cultivar) to 12.8% (in the *Izalco CS* cultivar) during the 2021-2022 season. On average over the two seasons, the highest protein content was observed in the *FDLGPC2* cultivar (11.8%). Cultivars showing significant differences from the trial average for grain protein content included *FDLGPC2, Alessio, Izalco CS, Arnold, Mv Suba, Viola, Mv Magdaléna, FDL Amurg* (Table 2).

According to the Grading Manual of Romania (https://www.gradare.ro/manual-de-gradare), minimum accepted percent protein for wheat is 11%. Grain protein percent of 12% is considered grade 1, and grain protein percent of 11% is considered grade 2. Grain protein percent under 11% is not regulated (in Romania the legislation related to the cereal grading is the same for both conventional and organic systems). In certain European countries, such as the UK, minimum protein for bread wheat is 13% (group 1), whereas for biscuit wheat, is 11.0-11.5% (group 3) according to the NABIM (National Association of British and Irish Millers) scheme (http://www.nabim.org.uk).

In our study, eight cultivars had protein percent over 11%: *Alessio, Arnold, Izalco CS, Mv Magdaléna, Mv Suba, FDLGPC2, FDL Amurg, Viola* (Table 2).

The best cultivars for the water absorption phase ("initslope") were: *Alessio, Arnold, Mv Magdaléna, Mv Suba, Mv Elit CCP, Mv Toborzó, FDL Amurg, Mv Mente, A15, Unitar, PS Dobromila, Bánkúti-1201, Ehogold, IS Laudis, FDL Miranda*. Cultivars exhibiting superior mixing requirements of the dough ("peaktime") included: *Voinic, Mv Karizma, Dacia, Aurelius, Anapurna, FDL Bogdana, Stanislava, Arnold, IS Gordius, NS Ilina*. For the dough strength or elasticity parameter ("peakheight"), cultivars significantly better than the trial average were *Alessio, Arnold, Izalco CS, Mv Magdaléna, Mv Suba, Mv Elit CCP, Mv Toborzó, PS Dobromila, Mv Mente, FDL Amurg, Bánkúti-1201, FDLGPC2, Mv Kolo, A15, BC Lira, PS Kvalitas, Ehogold*. Regarding the dough stability or tolerance to over-mixing parameter ("breakdown"), some cultivars had significant differences from the trial average, including *Mv Magdaléna, Radosinska Karola, Mv Suba, IS Mandala, Alessio, Mv Elit CCP, Mv Toborzó, IS Laudis, FDL Miranda*. The best cultivars for the dough extensibility parameter ("endwidth"), were *Mv Karizma, Mv Mente, Voinic, Pitar, FDL Abund* with a significant difference from the trial average (Table 2).

Estimated bread volume ranged from 414 cm^3/100 g flour (in the *Mv Káplár* cultivar) to 876 cm^3/100 g flour (in the *Alessio* cultivar) during the 2020-2021 season and from 416 cm^3/100g flour (in the *Mv Káplár* cultivar) to 934 cm^3/100 g flour (in the *Izalco CS* cultivar) during the 2021-2022 season. On average over the two seasons, the highest bread volume estimated by Reomixer was observed in the *Alessio* cultivar (814 cm^3/100 g flour). Cultivars showing statistically significant differences from the trial average for bread volume estimated with Reomixer included *Alessio, Arnold, Izalco CS, Mv Magdaléna, Mv Suba, Mv Elit CCP, PS Dobromila, Mv Toborzó, FDLGPC2, FDL Amurg, Bánkúti-1201, Viola, Mv Kolo, BC Lira, PS Kvalitas, Mv Mente* (Table 2).

Not all cultivars with significant differences from the average trial for bread volume also exhibited superiority across all rheological parameters. For example, *Mv Magdaléna* and *Mv Suba* cultivars were superior to the average trial for water absorption phase, dough strength (elasticity) and dough stability, but inferior for extensibility and *Viola* cultivar was inferior to the average trial for water absorption phase. The following cultivars had one or two rheological parameters superior to the average trial, but were not highlighted for bread volume (*Ehogold, A15, Mv Karizma, IS Mandala, Voinic, Radosinska Karola, IS Laudis, Pitar, Unitar, Stanislava, FDL Miranda, Aurelius, Dacia, FDL Bogdana, Anapurna, FDL Abund, NS Ilina)*. Also, not all the sixteen genotypes with statistically significant differences from the average trial for bread volume had higher protein content. Cultivars such as *BC Lira, Mv Mente, Mv Toborzó* achieved an estimated bread volume over 650 cm^3/100 g flour with approximately 10% protein (Table 2).

Table 2. The cultivars with significant differences from the average of the trial for the quality parameters

Wheat cultivar	Average values and significances						
	Protein %	Initslope	Peaktime	Peakheight	Breakdown	Endwidth	Estimated bread volume
Alessio	11.58***	8.3***	3.75	4.9***	1.4*	1.32	814***
Arnold	11.30**	7.9**	5.3*	4.8***	0.93	1.46	802***
Izalco CS	11.52**	7.06	4.98	4.4***	0.75	1.27	766***
Mv Magdaléna	11.13*	8.4***	1.86	4.7***	2.7***	0.63	763***
Mv Suba	11.22*	8.5***	3.28	4.5***	1.6**	0.69	731***
Mv Elit CCP	10.65	8.8***	2.37	4.5***	1.5*	1.00	704***
PS Dobromila	10.83	7.5*	4.08	4.1***	1.06	1.11	701***
Mv Toborzó	10.06	8.1***	2.59	4.3***	1.4*	0.88	696**
FDLGPC2	11.84***	6.88	4.48	3.9**	0.74	1.09	694**
FDL Amurg	11.09*	7.9***	3.89	4.1***	0.98	1.23	689**
Bánkúti-1201	10.91	7.7*	2.54	4.1***	1.10	0.72	683**
Viola	11.18*	5.08	4.38	3.46	0.80	0.85	670*
Mv Kolo	10.89	7.12	3.18	3.9**	0.93	0.81	662*
BC Lira	9.95	6.22	3.85	3.8*	1.33	0.85	660*
PS Kvalitas	10.94	7.26	3.95	3.8*	1.04	0.91	658*
Mv Mente	9.87	8.0***	4.92	4.1***	0.67	1.5*	653*
Ehogold	10.31	7.5*	2.75	3.8*	0.80	1.04	643
A15	10.15	8.0***	2.10	3.9**	1.01	0.87	630
Mv Karizma	9.94	6.16	6.5***	3.45	0.23	1.7**	619
IS Mandala	10.36	7.21	2.37	3.58	1.6**	0.84	607
Voinic	10.46	6.37	6.5***	3.40	0.31	1.5*	602
Radosinska Karola	10.85	7.16	1.64	3.46	2.4***	0.73	598

Wheat cultivar	Average values and significances						
	Protein %	Initslope	Peaktime	Peakheight	Breakdown	Endwidth	Estimated bread volume
IS Laudis	9.83	7.6*	1.83	3.57	1.4*	1.04	592
Pitar	9.61	6.99	2.19	3.46	0.72	1.6*	590
Unitar	8.93	7.7**	1.22	3.59	1.15	0.90	581
Stanislava	10.44	5.69	5.8**	3.11	0.30	1.02	568
FDL Miranda	9.33	7.5*	1.94	3.46	1.5*	1.04	567
Aurelius	10.21	5.87	6.1**	3.10	0.33	1.16	565
Dacia	10.76	6.26	6.6***	3.33	0.18	1.16	585
FDL Bogdana	10.28	5.94	6.4**	2.92	0.21	1.31	535
Anapurna	9.85	5.29	6.1**	2.74	0.25	1.14	523
FDL Abund	9.34	6.24	1.40	2.84	0.31	1.5*	510
NS Ilina	9.71	6.11	5.3*	2.90	0.35	1.00	510
IS Gordius	9.8	5.76	5.8**	2.64	0.12	1.46	498
Average	**10.04**	**6.70**	**3.3**	**3.33**	**0.72**	**1.09**	**579**
LSD 5%	**0.9**	**0.76**	**1.86**	**0.39**	**0.64**	**0.38**	**69.74**

*** - significant for P>0.01; ** - significant for P>0.1; * - significant for P>0.5.

In the last years breeders have searched for wheat genotypes with better breadmaking quality, even at lower protein content. Nine of the sixteen wheat genotypes with statistically significant differences from the trial average for bread volume contained subunits of HMW glutenin *5+10*, coded by *Glu-D1d* allele with the known greatest positive effect on breadmaking quality (Table 3). These subunits were detected, by molecular marker assay, in most genotypes (87%). In this study the varieties with the HMW glutenin *5+10* subunits showed positive effect on development time ("peaktime") and extensibility ("endwidth") (Table 4).

Table 3. The cultivars with statistically significant differences from the average trial for bread volume and molecular markers genetic profile at *Glu-A1*, *Glu-D1*, *Glu-B3g* and *NAM-A1* loci

No	Wheat variety	*Glu-A1*	*Glu-D1/Dx*	*Glu-D1/Dy*	*Glu-B3g*	*NAM-A1 haplotype*
1	Alessio	Ax1/Null	Dx2	Dy12	B3g	A1c
2	**Arnold**	Ax2*	**Dx5**	**Dy10**	B3g	A1c
3	**Izalco CS**	Ax2*	**Dx5**	**Dy10**	non B3g	A1a
4	Mv Magdaléna	Ax2*	Dx2	Dy12	B3g	A1c
5	**Mv Suba**	Ax2*	**Dx5**	**Dy10**	non B3g	A1c
6	Mv Elit CCP	Ax2*	H	H	non B3g	A1c
7	**PS Dobromila**	Ax1/Null	**Dx5**	**Dy10**	B3g	A1c
8	Mv Toborzó	Ax2*	Dx2?	Dy12?	non B3g	A1d
9	**FDLGPC2**	Ax1/Null	**Dx5**	**Dy10**	non B3g	A1c
10	**FDL Amurg**	Ax2*	**Dx5**	**Dy10**	non B3g	A1a
11	Bánkúti-1201	Ax2*	Dx2	Dy12	non B3g	A1c
12	**Viola**	Ax1/Null	**Dx5**	**Dy10**	non B3g	A1c
13	Mv Kolo	Ax1/Null	NA	Dy10	non B3g	A1c
14	**BC Lira**	Ax2*	**Dx5**	**Dy10**	non B3g	A1d
15	**PS Kvalitas**	Ax1/Null	**Dx5**	**Dy10**	B3g	A1c
16	MV Mente	Ax2*	Dx2	Dy12	non B3g	A1c

Bold = genotypes with subunits of HMW glutenin *5+10*.

The subunit Ax2* (detected in 50% cultivars) showed a positive effect on bread volume, water absorption phase, dough strength, and extensibility. In this study, a positive effect on development time was observed for the *Glu-B3g* allele. The most important locus studied seems to be *NAM-A1*. Molecular marker analysis in this germplasm revealed three haplotypes, with *NAM-A1c* having the highest frequency (51%), followed by *NAM-A1d* (38%) and *NAM-A1a* (11%) (Table 4). Both *NAM-A1a* and *NAM-A1c* haplotypes showed a positive effect on grain protein percent, bread volume, water absorption phase, dough strength and extensibility. These findings suggest that, in organic system, the *NAM-A1* locus has a positive effect on both protein content and quality.

However, these genes alone could not explain the entire variation in quality parameters, as some of the best cultivars possessed unfavorable alleles, while other cultivars carrying good alleles exhibited low quality. Obviously, other factors strongly influenced quality parameters in organic agriculture, and further research is needed to understand their nature.

Table 4. Summary of phenotype data grouped by genotype

Loci	No. Variants	Haplotype	Heading-21	Heading-22	Plant Height-21	Plant Height-22	Protein-21	Protein-22	Protein 21-22	BV21-22	Initslope21-22	Peaktime21-22	Peakheigh21-22	Breakdown21-22	Endwidth21-22
Glu-A1	41	Ax1/Null	135	135	96.5	85.2	9.7	10.4	10.1	569	6.5	3.4	3.2	0.72	1.06
	41	Ax2*	134	134	92.6	80.6	9.7	10.2	10.0	589	6.9	3.2	3.4	0.74	1.13
Glu-D1/Dy	69	Dx5+Dy10	134	134	93.7	82.2	9.7	10.3	10.0	568	6.6	3.3	3.2	0.67	1.11
	10	Dx2+Dy12	135	134	100.7	87.9	9.9	10.5	10.2	642	7.4	3.0	3.9	1.05	1.00
Glu-B3	44	B3g	135	135	93.7	82.6	9.7	10.4	10.0	574	6.6	3.5	3.3	0.68	1.08
	39	non B3g	134	134	95.7	83.2	9.8	10.3	10.0	584	6.9	3.0	3.4	0.78	1.11
NAM-A1	9	A1a	134	134	92.7	81.5	9.8	10.5	10.1	586	6.6	3.6	3.3	0.58	1.19
	41	A1c	129	135	55.0	98.1	10.6	10.0	10.3	602	6.8	3.3	3.5	0.81	1.07
	30	A1d	128	134	52.0	90.5	10.1	9.4	9.7	547	6.5	3.3	3.1	0.67	1.09

Uthayakumaran et al. (1999) showed that the mixing time, dough strength, extensibility and bread volume were higher at higher protein content. Other research found no effect of grain protein content on the mixing time ("peaktime") or the dough extensibility ("endwidth") and the effect on the dough strength ("peakheight") or bread volume was only on lower levels of grain protein content (Ciobănescu, 2008). Some researchers found positive significant correlations between mixing parameters and bread volume (Khatkar et al., 1996). Ciobănescu (2008) found positive significant correlation between bread volume and extensibility, only under fertilisation conditions.

In the present study, we found positive significant correlations between grain protein content and all breadmaking parameters, except extensibility („endwidth"). Estimated bread volume was strongly positively correlated with water absorption phase („initslope"), dough strength („peakheight") and dough stability („breakdown"). Water absorption ("initslope") was positively correlated with dough strength ("peakheight") and dough stability („breakdown") and negatively correlated with mixing time ("peaktime"). The mixing time was positively correlated with extensibility ("endwidth") and negatively correlated with dough stability („breakdown"). The dough strength ("peakheight") was positively correlated with dough stability („breakdown"). The dough stability („breakdown") was negatively correlated with extensibility ("endwidth") (Table 5).

Table 5. Summary of phenotype data grouped by genotype

	Protein %	BV	Initslope	Peaktime	Peakheight	Breakdown	Endwidth
Protein %	1						
BV	**0.81**	1					
Initslope	**0.42**	**0.70**	1				
Peaktime	**0.34**	0.18	*-0.31*	1			
Peakheight	**0.73**	**0.98**	**0.83**	0.06	1		
Breakdown	**0.42**	**0.61**	**0.67**	*-0.36*	**0.67**	1	
Endwidth	-0.16	-0.09	-0.09	**0.27**	-0.12	*-0.53*	1

bold numbers = positive correlations for P>0.01;
italic numbers = negative correlations for P>0.01.

The quality parameters must be analyzed in correlation with the grain yield. In our study there was no correlation between yield and protein %, but there was a negative correlation between yield and estimated bread volume (Figures 1 and 2).

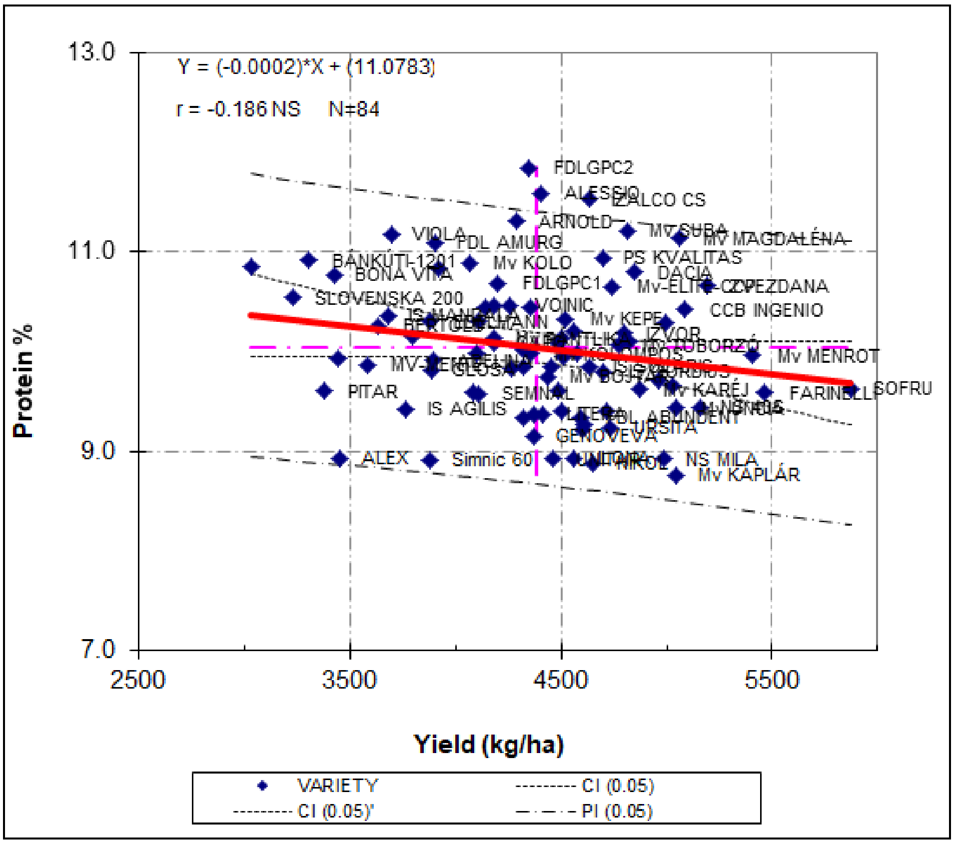

Figure 1. Correlation between grain yield and grain protein content, in organic conditions, during two seasons, 2020-2021, 2021-2022

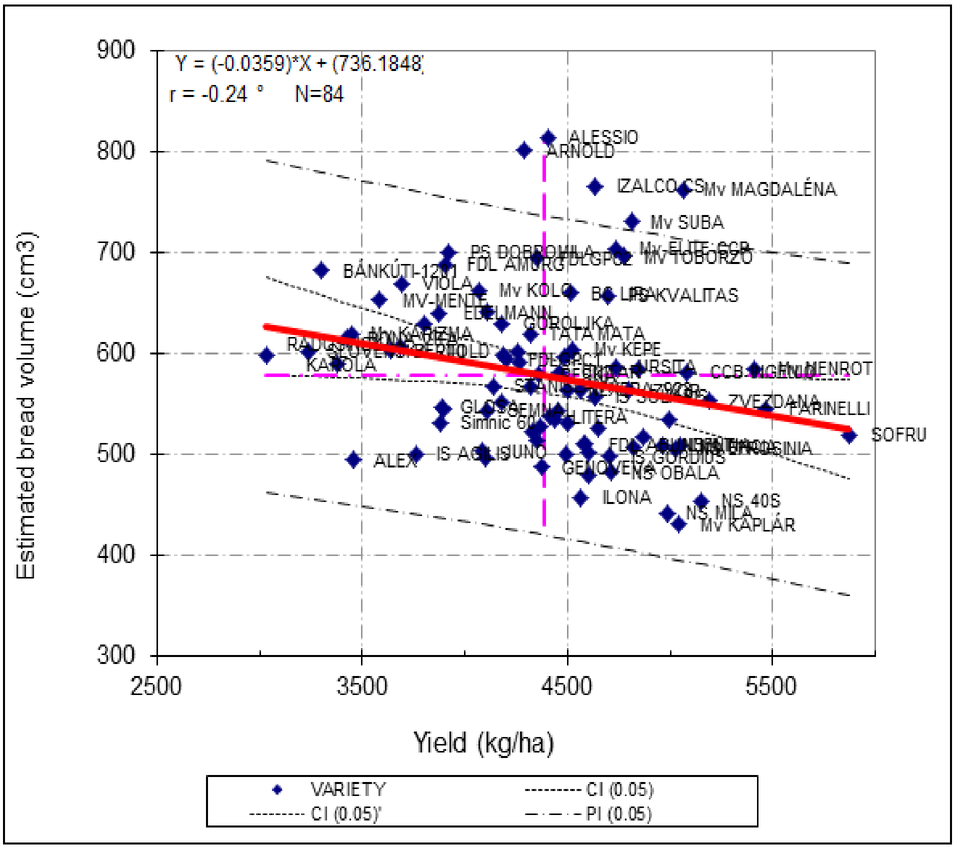

Figure 2. Correlation between grain yield and estimated bread volume, in organic condition, during two seasons, 2020-2021, 2021-2022

In breeding programs cultivars with positive deviations from the regression are the most interesting. Sixteen cultivars exhibited positive deviations, over 50 cm^3/100 g flour, from the regression of estimated bread volume on yield (Table 6).

Table 6. Deviations from the regression estimated bread volume - yield, for sixteen cultivars, tested in organic conditions

No	Cultivars	Average yield (kg/ha)	Average bread volume (cm^3/100 g flour) estimated by Reomixer	Bread volume predicted by the regression of BV on yield	Deviations from regression
1	Alessio	4404	814	578.23	+235.52
2	Arnold	4288	802	582.39	+219.11
3	Mv Magdaléna	5066	763	554.51	+208.49
4	Izalco CS	4637	766	569.89	+195.86
5	Mv Suba	4814	731	563.54	+166.96
6	Mv Elit CCP	4739	704	566.24	+137.76
7	Mv Toborzó	4772	696	565.03	+130.97
8	FDLGPC2	4352	694	580.12	+114.13
9	PS Dobromila	3922	701	595.54	+105.46
10	FDL Amurg	3903	689	596.22	+92.78
11	PS Kvalitas	4701	658	567.59	+90.41
12	BC Lira	4514	660	574.30	+85.45
13	Mv Kolo	4069	662	590.24	+72.01
14	Viola	3697	670	603.61	+66.39
15	Bánkúti-1201	3303	683	617.73	+65.02
16	Ehogold	4112	643	588.73	+53.77

Other researchers (Hassan and Gul, 2006; Khalid et al., 2023) also considered that wheat production and quality could be enhanced through the development of new and improved varieties that are able to produce a superior yield and perform better under various agro-climatic stresses and conditions. It is the common consensus that the diversity of germplasm in breeding material is an essential component in plant breeding (Bibi et al., 2012; Khalid et al., 2022; Khalid et al., 2023).

CONCLUSIONS

Significant differences were observed among 84 winter wheat cultivars tested under organic agriculture, regarding the quality parameters. Sixteen cultivars exhibited statistically significant differences from the average trial for bread volume (over 650 cm^3/100 g flour). Molecular analyses revealed that nine of these sixteen cultivars, demonstrating suitable values for bread volume, carry subunits of HMW glutenin *5+10*, encoded by *Glu-D1d* allele, known to have the greatest positive effect on breadmaking quality. This suggests the possibility of developing varieties with improved breadmaking quality in organic conditions through genetic approaches. However, combining suitable breadmaking quality with high yield will remain a challenge. In our study, a negative correlation between grain yield and estimated bread volume was observed. Some of the tested varieties showed positive deviations from the regression grain yield - quality parameters. The results indicated a positive influence of the *NAM-A1c* haplotype and Glu-A2* subunit on bread volume. The *NAM-A1* locus was found to have a positive effect on both protein content and quality.

ACKNOWLEDGEMENTS

Results presented in this paper were obtained in the frame of the European research project ECOBREED (“Increasing the efficiency and competitiveness of organic crop breeding”), H2020 - Grant agreement ID: 771367, financed by the European Union.

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