NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 42, 2025
www.incda-fundulea.ro; doi.org/10.59665/rar4214 First Online: February, 2025. DII 2067-5720 RAR 2025-104

Direct Multi-trials Estimation of Genetic Progress in Wheat Breeding at NARDI Fundulea, Romania

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ABSTRACT

Genetic progress for grain yield in wheat breeding at NARDI Fundulea, estimated by direct comparison of nine cultivars registered during 2005-2025 in 48 yield trials from Southern and Western Romania and sixteen yield trials from Central and Eastern Romania conducted for four years (2021-2024), was 49 kg/ha/year and 44.8 kg/ha/year, respectively. The yield increase obtained by the highest yielding recent cultivar (*FDL Columna*) over *Glosa* was 703 and 777 kg/ha in the two zones. This yield increase is additional to the 1184 kg/ha, and 1581 kg/ha increase previously recorded by *Glosa* over *Bezostaya 1.* All new cultivars had yield coefficients of variation smaller than *Glosa* in Southern and Western Romania, while in the Central and Eastern part of the country only two cultivars had better yield stability than *Glosa*.

Genetic progress for yielding potential, estimated by the maximum yield recorded for each cultivar in any of the trials from the two zones, was 70.5 and 51.1 kg/ha/year, respectively, while for minimum yield we only observed a nonsignificant trend of increase of 12.1 kg/ha/year. Under reduced Nitrogen fertilization we observed a significant genetic progress of 40.7 and 47.1 kg/ha/year, respectively, while in the organic agriculture system we found a nonsignificant trend of increased yields of 27.1 kg/ha/year.

Most of the new cultivars had a grain protein concentration higher than *Glosa*, and cultivar *FDL Columna*, which was on average the highest yielding also had the highest grain protein concentration averaged on twenty-three trials.

We found significant genetic progress for resistance to *Fusarium* head blight, with cultivar *FDL Consecvent* proving to be the most resistant for four years under artificial inoculation.

The superior performance of the most recent cultivars might be related to the fact that they carry introgressions from rye or from *Aegilops ventricosa*.

Keywords: genetic progress, wheat, yielding potential, stress, reduced fertilization, *Fusarium*.

INTRODUCTION

Use of high-yielding cultivars, adapted to environmental conditions is essential for wheat production. Wheat breeding programs all over the world continuously achieved genetic progress for yield and for many other traits. Many researchers estimated the effects of breeding by comparing cultivars released during various periods, either by comparing them directly or by comparisons with common checks. Because of confounding effects of climate or crop management changes, direct comparisons are more reliable and have been widely used. Brancourt-Hulmel et al. (2003) summarized reports of genetic gains estimated through direct comparison of old and new cultivars. We added to their summary more recent reports, published after 2003 (Table1). The genetic gains for yield reported by various breeding centers around the world varied from less than 10 kg/ha/year in the stressful conditions of Australia to more than 150 kg/ha/year in the most favorable, high rainfall areas where the tests organized by the International Center for Maize and Wheat Improvement (CIMMYT) were conducted (Table 1).

Received 31 December 2024; accepted 3 February 2025.

Table 1. Assessment of genetic gain in wheat yield: from a direct comparison of cultivars grown simultaneously (modified from Brancourt-Hulmel et al., 2003)

Country	Period	Number of genotypes	Gain (kg ha^{-1} yr^{-1})	Reference
Western Australia	1884-1982	27	5.8	Perry and d'Antuono, 1989*
Sweden	1900-1970	20	12.6	Ledent and Stoy, 1988*
USA (North Dakota)	1911-1979		14.0	Deckerd et al., 1985*
USA (Great Plains)	1919-2008	30	14.6	Battenfield et al., 2013
Germany	1921-1978	10	15.8	Karpenstein-Machan and Scheffer, 1989*
USA (Kansas)	1919-1987	38	16.0	Cox et al., 1988*
India	1900-2016	10 and 14	24.3-29.3	Yadav et al., 2021
Mexico	1965-2014	30	24.7-35.3	Mondal et al., 2020
China	1940-2010		26.0-91.0	Chen et al., 2024*
Brazil	1940-2009	10	29.0	Beche et al., 2014
UK	1908-1978	12	30.0	Austin et al., 1980*
Mexico NW	1966-2009	12	30.0	Aisawi et al., 2015
UK	1908-1985	13	38.0	Austin et al., 1989*
France	1918-1938	5	39.0	Jonard and Koller, 1951*
Serbia	1913-2015	10	46.4	Mirosavljević et al., 2024
France	1925-1978	10	50.0	Masle, 1985*
Mexico (N-W)	1950-1982	14	59.0	Waddington et al., 1986*
France	1970-2011		65.0-137.0	Oury et al., 2012
CIMMYT - High rainfall - Low rainfall	2007-2016		 65.1-160.0 40.0-33.1	Gerard et al., 2020

*Cited by Brancourt-Hulmel et al. (2003)

The National Agricultural Research and Development Institute Fundulea (NARDI Fundulea) has been long involved in providing adapted cultivars to Romanian farmers. Since 1958, when the NARDI wheat breeding program was established, it released thirty-four common wheat cultivars, which have been grown from 1971 to the present on about 40 to 69 % of the total wheat acreage in Romania (Săulescu et al., 2007; INCS Databases, 2023). Genetic progress for yield provided by these cultivars was estimated, for different periods from 1961 to 2005, between 34 and 60 kg/ha/year (Săulescu, 1983; Săulescu et al., 1998; Mustățea and Săulescu, 2011).

The present paper presents a new estimation of genetic progress obtained in cultivars released after 2005, based on direct comparisons in multiple trials conducted during four years across Romania.

MATERIAL AND METHODS

To estimate genetic progress, we analyzed yield trials results obtained in nine winter wheat cultivars released from the National Agricultural Research and Development Institute Fundulea, Romania, during the period 2005-2025, along with the historical check *Bezostaya 1*. Yield trials with balanced lattice design, on 5 or 10 m^2 plots with three replications, were organized in two zones.

The first zone, representing the South and West of Romania, included yield trials conducted at:

- Agricultural Research and Development Station (ARDS) Valu lui Traian - Lat. 44º16' N, Long. 28º51'E;
- National Agricultural Research and Development Institute Fundulea (NARDI Fundulea) - Lat 44°30`N, Long 26°51`E. At this site two trials with different sowing dates were analyzed;
- Agricultural Research and Development Station (ARDS) Teleorman (Drăgăneşti-Vlaşca) - Lat. 44°07'N, Long. 25°45'E;
- Agricultural Research and Development Station (ARDS) Mărculeşti - Lat. 44°25′N, Long. 27°29′E;
- Agricultural Research and Development Station (ARDS) Brăila - Lat. 45°16′N, Long. 27°57′E;

- Agricultural Research and Development Station (ARDS) Piteşti - Lat 44º81'N, Long. 24º86'E;
- Craiova University - Agricultural Research and Development Station (ARDS) Caracal - Lat. 44º11'N., Long. 24º37'E;
- Agricultural Research and Development Station (ARDS) Șimnic - Lat. 44°20′N, Long. 23°49′E;
- Agricultural Research and Development Station (ARDS) Lovrin - Lat. 45°57'N, Long. 20°46';
- Agricultural Research and Development Station (ARDS) Oradea - Lat. 47°02'N, Long. 21°54'E;
- Agricultural Research and Development Station (ARDS) Livada - Lat. 47°52'N, Long. 23°08'E;

The second zone, representing the Central and Eastern Romania, included yield trials conducted at:

- Agricultural Research and Development Station (ARDS) Turda - Lat. 46º58' N, Long. 23º78'E;
- Research and Development Station for Cattle Breeding (RDSCB) Târgu Mureş - Lat. 46°32'N, Long. 24°33'E;
- Agricultural Research and Development Station (ARDS) Secuieni - Lat. 46ºN, Long. 26º86'E;
- Agricultural Research and Development Station (ARDS) Perieni - Lat. 46°18′N, Lat. 27°37′E.

The testing sites covered a large diversity of soils, from chernozems to luvisoils, with pH from 5.02 to 7.6, and humus content from 1.71 to 3.6%. Weather conditions during the period 2021-2024 at all these sites reflected present climate changes and were diverse, as illustrated by rainfall during the vegetation period, which varied from 211.2 to 613.8 mm.

Crop management of these trials was the one recommended for each environment, including the recommended Nitrogen fertilization, which varied from 82 to 143 kg N/ha.

We used results from yield trials conducted for four years (2021-2024), totaling forty-eight trials in zone 1 and 16 trials in zone two, and analyzed for each cultivar the average yield, maximum yield (as an approximation of yielding potential) and minimum yield (as a measure of reaction to unfavorable conditions).

To understand to what extent genetic progress for yield was reflected in various crop management conditions we also analyzed results of:

- Twenty trials performed during 2021-2024 in zone one at ARDS Valu lui Traian, ARDS Teleorman, ARDS Caracal, ARDS Piteşti and NARDI Fundulea, and seven trials in zone two at ARDS Turda and ARDS Secuieni, where cultivars were also tested with reduced N fertilization, varying from 0 to 50 kg N/ha, applied only in autumn;
- Four trials from NARDI Fundulea and ARDS Valu lui Traian, where cultivars were tested under organic agriculture system in 2023 and 2024.

Fusarium head blight resistance, was estimated by Area under Disease Progress Curve, averaged on four years (2021-2024) after injecting *Fusarium* spores into central spikelets, as described by Galit et al. (2024). Grain protein concentration was determined spectrophotometrically at NARDI Fundulea, ARDS Turda and ARDS Secuieni, using samples from twenty-three yield trials.

We estimated genetic progress by the slope of the regression of cultivar performance on the year of release and used correlation analysis to estimate the significance of the relationship. We also used correlations to analyze the relationship between cultivar yields in different conditions. To estimate yield stability of studied cultivars we used the coefficient of yield variation (s%).

RESULTS AND DISCUSSION

Regressions describing the evolution of average grain yield according to the year of release of studied cultivars had slopes of 49.1 kg ha^{-1} per year in first zone (where the breeding program is located) and 44.8 kg ha^{-1} per year in second zone. Both regressions were highly significant, with values of coefficient of correlation (r) of 0.88 and 0.89. The highest yielding cultivar in both zones (*FDL Columna*) over yielded the cultivar *Glosa* on average of 48 and 16 yield trials respectively by 703 and 777 kg ha^{-1}. This yield increase was additional to the yield difference of 1184 kg ha^{-1} or 1581 kg ha^{-1} between *Glosa* and the historical check *Bezostaya 1*, in first and second zone, respectively, which resulted from previous breeding during the period from 1958 to 2005 (Figure 1).

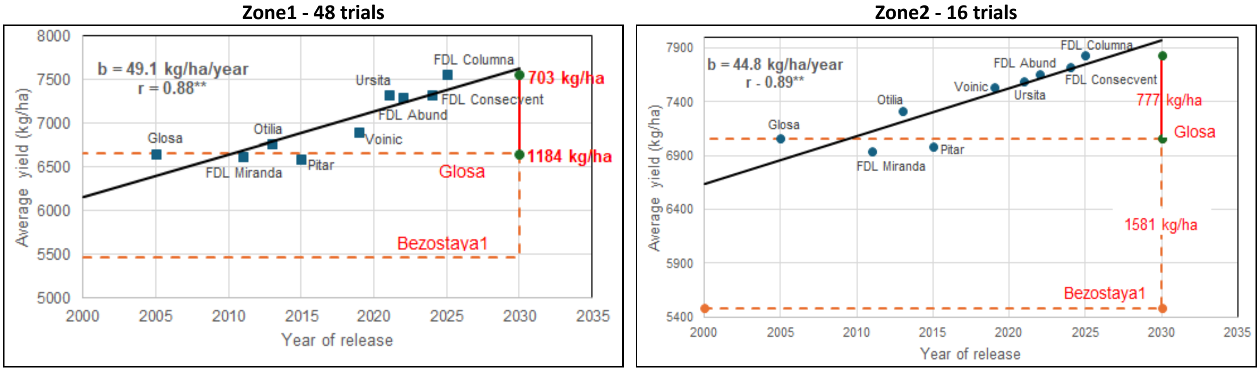

Figure 1. Genetic progress in average grain yield, based on direct comparison in multiple yield trials

We considered the yield variation of each cultivar in the studied trials, as reflected by the coefficients of variation, as an estimation of yield stability. As seen in Figure 2, coefficients of variation showed a non-significant negative trend, being smaller in more recently released cultivars.

All new cultivars had smaller coefficients of variation than *Glosa* in Zone1, while in Zone2 most cultivars were less or as stable than *Glosa*. The difference in coefficients of variation between *Glosa* and the cultivar with the lowest variation (*FDL Consecvent*) in zone1 was double than the difference between *Glosa* and *Bezostaya 1*, while in Zone2 the difference between *Glosa* and *Bezostaya1* was much larger than the one observed between *Glosa* and the recent most stable cultivar.

The fact that, with similar genetic progress for yield, coefficients of variation showed different evolution in the two zones suggests that other factors were involved in yield variation in the South and West regions of Romania than in the region of North and East. More research is needed to identify these factors and to breed for resistance or tolerance to these factors. Results also suggest breeding targets that should be considered a priority in future projects to increase wheat yield stability.

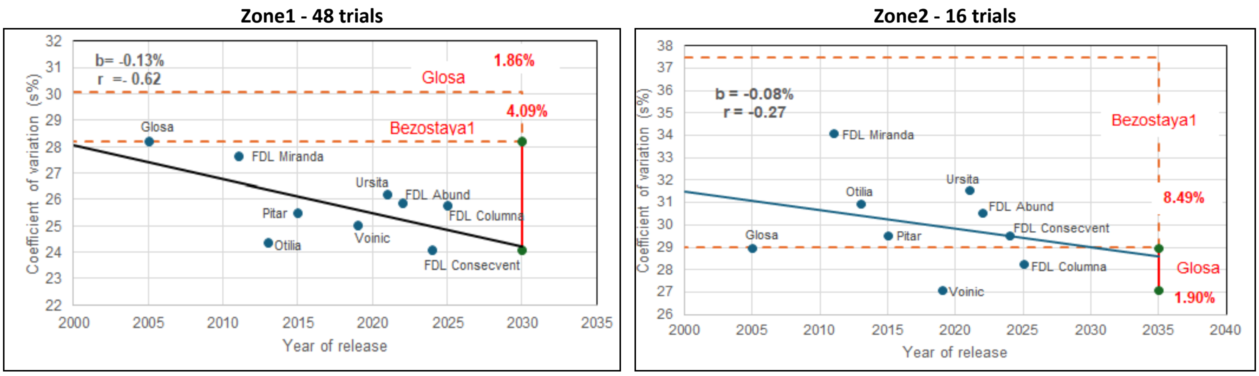

Figure 2. Coefficients of variation evolution in cultivars released from NARDI Fundulea during 2005-2025

To estimate genetic progress in yielding potential, we used the highest yield recorded in each analyzed cultivars in any of the trials from each zone. Progress during the last 20 years of breeding was larger than the one for average yield, slopes of regressions being 70.5 and 51.1 kg ha^{-1} per year for the two zones (Figure 3).

The difference between the cultivar *FDL Columna* (which had the highest maximum yield of more than 11000 kg ha^{-1} in Zone1) and *Glosa* was 1427 kg ha^{-}1, larger than the difference between *Glosa* and *Bezostaya 1*, which resulted from a much longer period of breeding. All cultivars released after 2005 had higher yielding potential than *Glosa*.

In Zone2, the highest yield was recorded in *FDL Abund*, which over yielded *Glosa* by 1081 kg ha^{-1}, and only the most recent cultivars showed higher yielding potential than *Glosa*.

In contrast with what we observed for average yields, the difference between the cultivar performance in the two zones was obvious, the earlier heading cultivars, such as *Voinic* and *Pitar*, having a more limited yielding potential in Zone2.

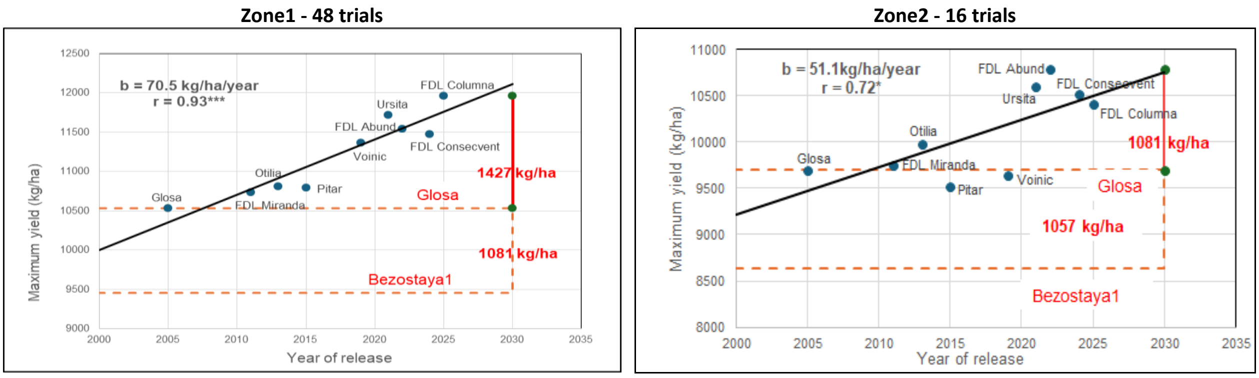

Figure 3. Genetic progress in maximum grain yield, recorded in any of the multiple yield trials

As the large variation in yields between trials was mostly determined by diverse levels of water stress, we considered the minimum yields, recorded in any of the trials, an estimation of cultivar stress response.

The evolution of minimum yields according to the release year of the cultivars showed only a non-significant positive trend, most cultivars producing lower or almost equal to *Glosa* in the most unfavorable conditions (Figure 4). Only cultivars recently released (*FDL Columna* and *FDL Consecvent*) in Zone1 and *Voinic* and *FDL Columna* in Zone2 over yielded *Glosa* in these conditions.

Obviously, breeding did not achieve so far progress in improving performance under unfavorable conditions, and increased efforts should be directed to stress resistance. The better performance of *FDL Columna*, which also had the highest yielding potential, suggests that it is possible to combine stress resistance with high yields, and this cultivar can be a suitable parent for this purpose. The yield advantage of the highest yielding cultivar over *Glosa* under unfavorable conditions was smaller than the one obtained earlier, from *Bezostaya 1* to *Glosa*.

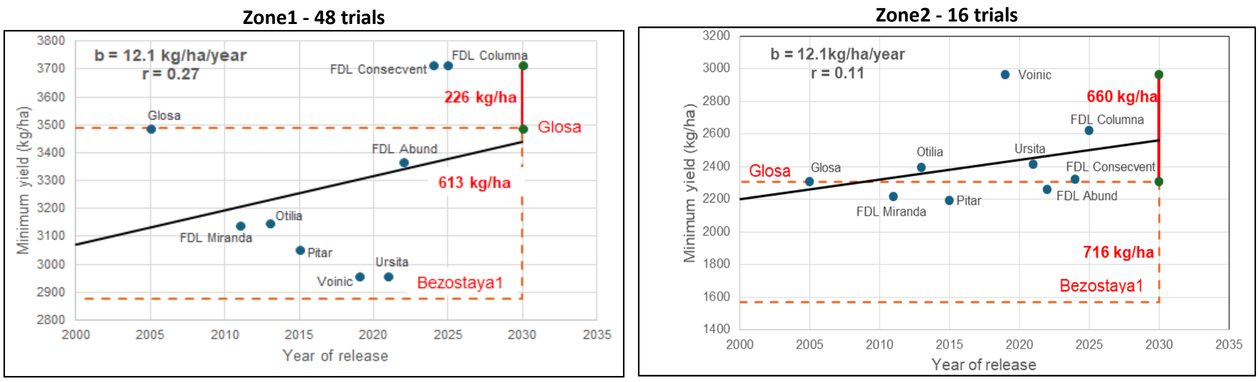

Figure 4. Genetic progress in minimum grain yield, recorded in any of the multiple yield trials

In yield trials with reduced Nitrogen fertilization, genetic progress was evident, with slopes of 40.7 and 47.1 kg ha^{-1} per year, significant at P<1% (Figure 5).

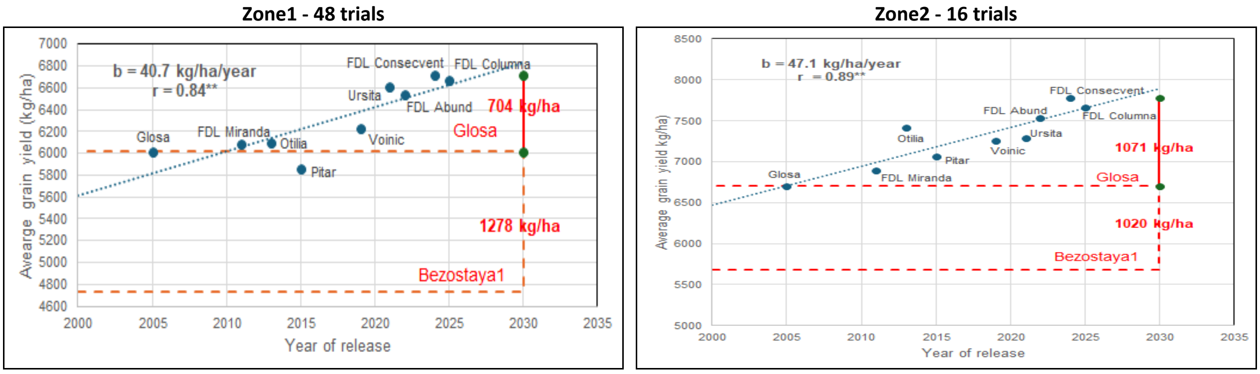

Figure 5. Genetic progress for grain yield, in trials with reduced Nitrogen fertilization

It is interesting to note that the highest yielding cultivar under N deficiency stress was *FDL Consecvent*, and this could suggest that this cultivar might have better N utilization efficiency. In the four yield trials performed with organic agriculture management, yield variation was not significantly correlated with the cultivar year of release. Highest yields under this agriculture system were recorded in cultivars *FDL Miranda* and *FDL Consecvent*. The performance of *FDL Miranda*, which is very susceptible to foliar diseases, could be explained by their reduced disease effect in organic agriculture, while the performance of *FDL Consecvent* coincides with its better results under reduced N availability.

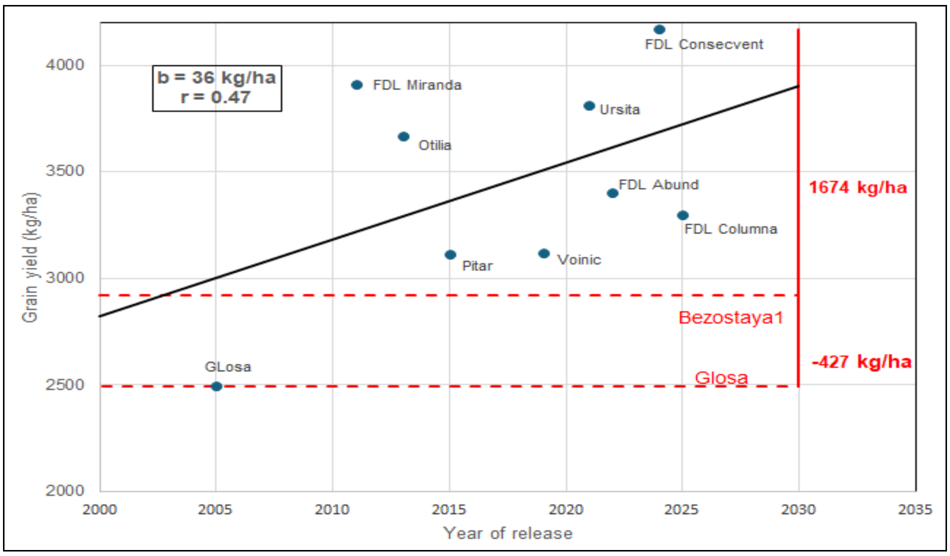

Figure 6. Grain yield variation in organic agriculture for cultivars released during 2005-2025

These results suggest that genetic progress achieved by breeding in conventional agriculture are also partially reflected under organic management, and this agrees with Marinciu et al. (2022) who stated that “The highest average grain yields in organic agriculture were obtained in the most recently released cultivars, which outyielded the cultivar *Glosa*, recommended based on previous research findings for organic farms”. This suggests that the genetic progress in yield obtained by breeding programs working under conventional agriculture can be reflected, at least partially, under organic agriculture.

Our genetic progress estimations for yield are similar with those reported in similar conditions and are among the most dependable, as they were based on direct comparisons in a large number of trials, covering diverse environmental conditions.

To understand the differences in genetic progress found between different conditions, we analyzed correlations between cultivar performance in these conditions (Table 2). Average yields of analyzed cultivars were strongly correlated with Maximum yields and the yields under reduced N fertilization in both zones and between zones, suggesting that yielding potential was the main factor in all these conditions. In contrast, minimum yields in zone one, determined mainly by water stress response, were not correlated with cultivar performance in the other conditions. In zone two, where minimum yields were also influenced by other factors, cultivar performance under most unfavorable conditions was correlated with the average yields and with yields obtained with reduced N fertilization. Yields obtained in organic agriculture showed in general less strong correlations, among which correlations with yields under reduced N fertilization are particularly interesting, as lower N availability is common with organic management.

Table 2. Correlations between cultivar performance in different conditions

	Average Zone1	Maximum Zone1	Minimum Zone1	Reduced N Zone1	Average Zone2	Maximum Zone2	Minimum Zone2	Reduced Zone2
Average Zone1	1							
Maximum Zone1	**0.98**	1						
Minimum Zone1	0.60	0.48	1					
Reduced N Zone1	**0.99**	**0.95**	0.59	1				
Average Zone2	**0.98**	**0.95**	0.55	**0.98**	1			
Maximum Zone2	**0.94**	**0.89**	0.56	**0.94**	**0.89**	1		
Minimum Zone2	*0.71*	*0.76*	0.23	*0.72*	**0.81**	0.49	1	
Reduced Zone2	**0.94**	**0.91**	0.56	**0.94**	**0.96**	**0.88**	*0.72*	1
Organic	*0.66*	0.59	0.35	*0.72*	0.61	**0.77**	0.23	*0.67*

Correlation coefficients written in **bold** are significant at P<1%;
Correlation coefficients written in *italic* are significant at P<5%.

Heading date and plant height were not correlated with the year of cultivar release and were not associated with the progress in yield (data not shown). All new cultivars headed earlier than *Bezostaya 1*, but only *FDL Columna* was as early as *Glosa*. All new cultivars were shorter than *Bezostaya 1,* as they are carriers of the dwarfing gene *Rht1Bb,* but they were not significantly different from *Glosa*, also a *Rht1Bb* semidwarf.

Average grain protein concentration showed a positive trend associated with the year of cultivars' release, although this relationship was not significant (Figure 7). Most new cultivars had higher average grain protein concentration than *Glosa* and the fact that *FDL Columna* had the highest grain protein percentage averaged on twenty-three trials, while being at the same time the highest yielding cultivar, is worth mentioning. Only cultivars *FDL Miranda* and *Ursita* had on average lower grain protein concentrations than *Glosa*.

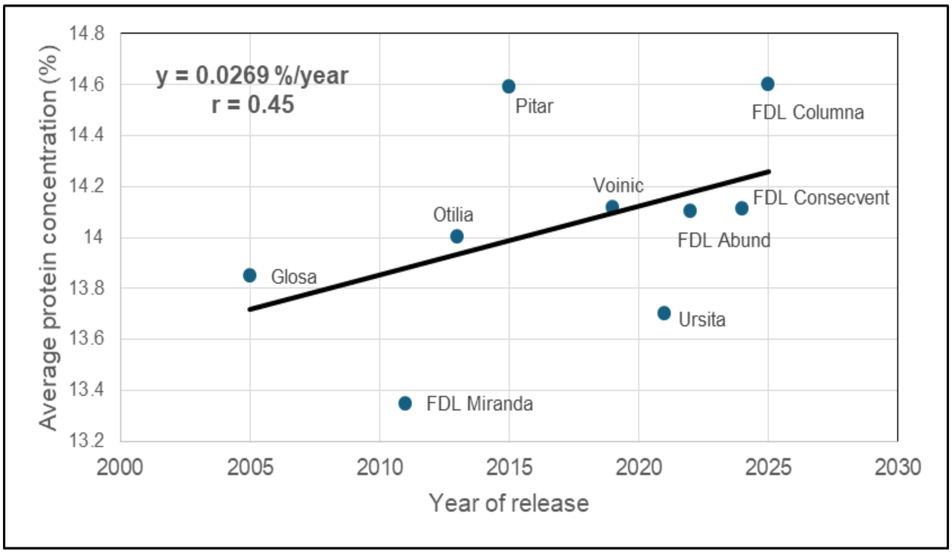

Figure 7. Evolution of grain protein concentration in cultivars released during 2005-2025

Grain protein concentration is affected by the known negative relationship with grain yield. To avoid this confounding effect, we calculated for each cultivar deviations from the regression of GPC on yield. These deviations were associated, close to significance, with the cultivar's year of release (Figure 8). Cultivars *FDL Columna* and *Pitar* had largest positive deviations from the regression, while *FDL Miranda* and *Ursita* had the largest negative ones.

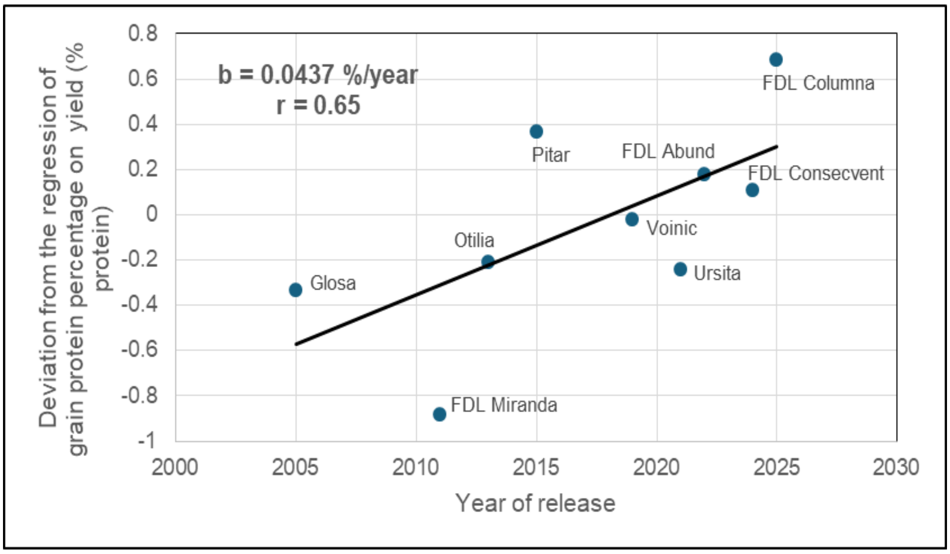

Figure 8. Deviations from regression of GPC on yield, for cultivars released during 2005-2025

Another trait where we observed genetic progress was the resistance to *Fusarium* head blight. All newer cultivars had AUDPC values smaller than *Glosa*, and *FDL Consecvent* was the most resistant to the attack of this important pathogen. Obviously, the continuous breeding effort, based on routine testing of breeding lines under artificial inoculations, resulted in a significant improvement of genetic protection against this disease. We believe that the advancement in FHB resistance could have contributed to yield stability of recently released cultivars.

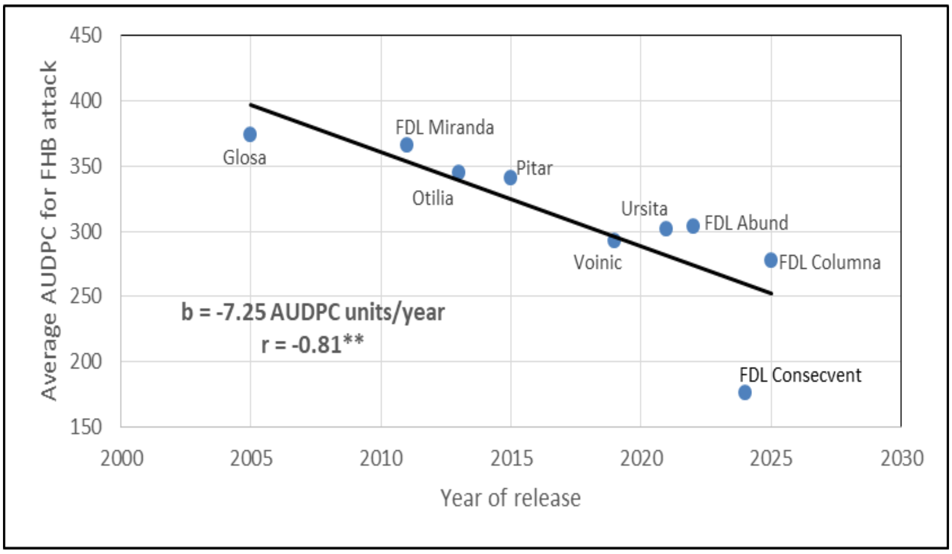

Figure 9. Genetic progress for resistance to Fusarium head blight in cultivars released during 2005-2025

Molecular marker analysis showed that:

- all recent cultivars carry the *Rht-B1b* allele for reduced height and the *Ppd* allele for day length insensibility.

- all recent cultivars carry the most favorable allele of the genes controlling the Glutenin fractions 2* and 5+10.

- cultivars *Ursita*, *FDL Abund* and *FDL Consecvent* carry a 1A-1R translocation from rye, transferred using *Triticale* as a bridge (Săulescu et al., 2011).

- cultivar *FDL Columna* carries the gene complex *Lr37-Yr17-Sr38*, associated with disease resistance, transferred from *Aegilops ventricosa* and the marker iw2 **(+)** associated with intense waxiness.

CONCLUSIONS

Wheat breeding based on gene recombination and selection, and supported by efficient pre-breeding, physiology tests and molecular marker selection, produced significant genetic progress for:

- average yield with recommended crop management;

- yielding potential estimated by maximum yields recorded for cultivars in any of the trials;

- average yield with reduced Nitrogen fertilization;

- *Fusarium* head blight resistance estimated under artificial inoculation in four years.

Yield increase was not associated with a reduction in grain protein concentration. Cultivar *FDL Columna* was the highest yielding and had the highest grain protein concentration.

We observed only a non-significant positive trend between the year of cultivar release and:

- stress tolerance, as estimated by the minimum yields recorded for cultivars in any of the trials;

- average yield in organic agriculture.

This can suggest priorities for future research and breeding.

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