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# Quantitative Analysis of Triticale Germplasm in Macro-region 1 of Romania

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## ABSTRACT

**Triticale (× *Triticosecale* Wittm.) is a hybrid cereal combining the agronomic advantages of wheat and rye, valued for its high yield potential, adaptability to marginal environments, and functional grain quality. In Romania, interest in triticale cultivation has increased in response to climate variability and the need for genotypes with improved productivity and nitrogen-use efficiency.**

**This study evaluated the quantitative performance of 25 winter triticale genotypes under two nitrogen fertilisation regimes ($N_{50}$ and $N_{100}$) over two growing seasons (2023-2024 and 2024-2025) in macro-region 1 of Romania (Turda), aiming to identify high-yielding and stable genotypes with superior agronomic and quality traits under moderate input conditions. Field experiments were conducted using a balanced square-grid design with six replications. The biological material included 10 commercial varieties and 15 advanced breeding lines. Grain yield and yield-related traits were assessed alongside quality parameters, including thousand kernel weight, test weight, grain protein content, and harvest index. Results showed strong genotype and year effects on yield and quality, while additional nitrogen had limited overall impact on yield. Several breeding lines (especially 18061T, 18013T, 18031T, and 18017T, along with the variety Zaraza) consistently achieved the highest yields (~9.4–9.9 t/ha). Yield stability was strongly influenced by genotype rather than fertilization level. Nitrogen increased protein content but also intensified the negative correlation between yield and grain quality. The best-performing genotypes combined high yield, acceptable protein levels, and stable harvest index across environments.**

**Keywords:** winter triticale adaptability, yield, quality, nitrogen response.

## INTRODUCTION

Triticale does not possess a natural ancestral progenitor, as it was created through deliberate hybridisation (Gașpar and Butnaru, 1985; Ittu et al., 2007). It combines desirable traits of its parental species, wheat (*Triticum* spp.) and rye (*Secale cereale* L.).

The history of triticale dates back to 1875, when the first wheat-rye hybrid was reported at the Edinburgh Botanical Society. In Romania, the species was first described by Nicolae Săulescu in 1927 in the article titled "*The Wheat-Rye Hybrid*", published in issue 12 of the journal *Viața agricolă*. The first variety of octoploid triticale was created in 1939 (Priadcencu, 1952); however, a systematic breeding effort for this species did not begin until 1971 at ICCPT Fundulea (Ittu et al., 2007).

Worldwide, due to the high yield potential, suitable agrotechnical properties, and nutritional value of the grain, the interest in growing triticale is increasing. Although winter triticale is cultivated on smaller areas than wheat or maize, it is valued for its high adaptability to less favourable growing conditions. In Romania, the area cultivated with winter triticale has fluctuated over time, exhibiting an overall downward trend. Since 2016, the area cultivated with triticale has decreased, dropping below 60,000 ha by 2024, as shown in Figure 1 (Brodeală et al., 2025). Yields ranged from 3,197 kg ha$^{-1}$ (2020) to 4,272 kg ha$^{-1}$ (2018), depending on genotype, environmental circumstances, and crop management.

Recent statistical data regarding the area sown with triticale and the average yields obtained in each macro-region (MR) in 2024

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are presented in Figure 2 (Brodeală et al., 2025). Macro-region 1, corresponding to Transylvania, has the largest area under triticale cultivation (23,805 ha), with an average yield of 3,524 kg ha$^{-1}$.

All agricultural cropping systems aim to achieve high, stable yields of excellent quality. The implementation of appropriate field management practices, the careful selection of suitable genotypes, and favourable agroclimatic conditions are key factors in attaining this objective (Madić et al., 2018). The interaction between genotype and environment determines the degree of adaptation. Throughout the vegetative cycle, plant development is influenced by both genetic and environmental factors, which ultimately determine the realisation of a genotype's genetic potential (Küçüközdemir et al., 2021). According to Postolati et al. (2019), the extent to which ecological conditions meet the agrobiological requirements of a genotype directly influences its level of performance.

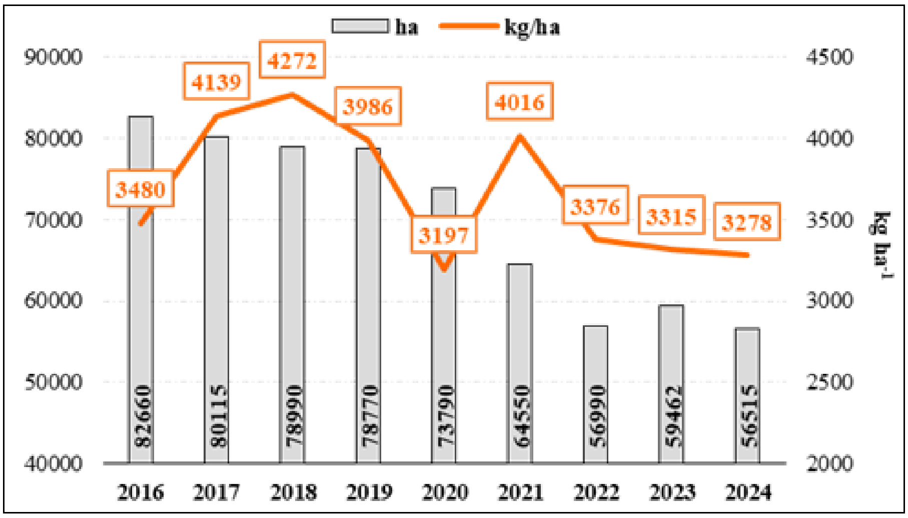
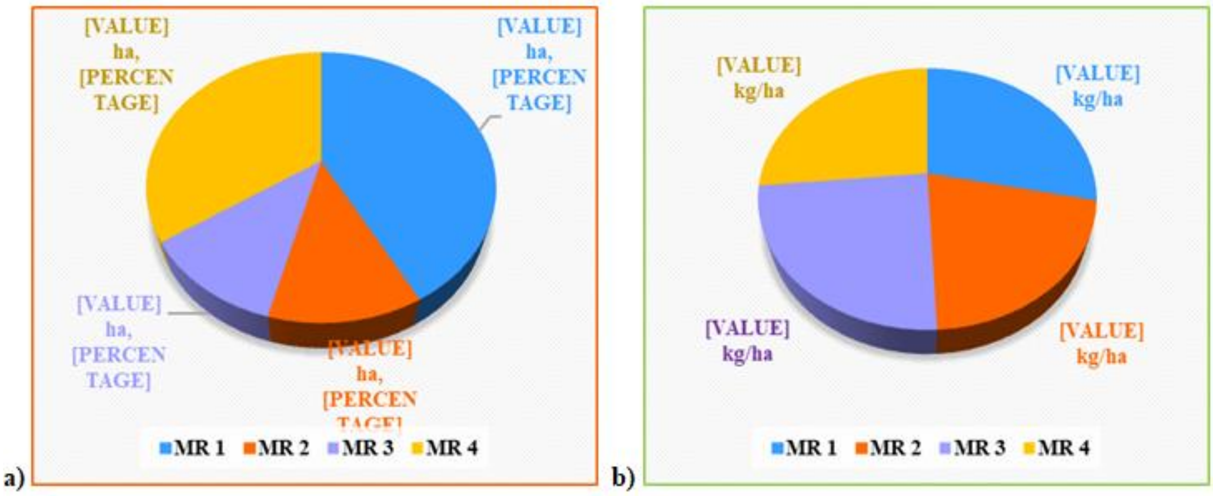



*Figure 1*. The evolution of average areas and yields for triticale in Romania




Note: **MR 1** comprises North-West (Bihor, Bistrița-Năsăud, Cluj, Maramureș, Satu Mare, Sălaj) and Centre (Alba, Brașov, Covasna, Harghita, Mureș, Sibiu); **MR 2** comprises North-East (Bacău, Botoșani, Iași, Neamț, Suceava, Vaslui) and South-East (Brăila, Buzău, Constanța, Galați, Tulcea, Vrancea); **MR 3** comprises Bucharest–Ilfov and South Muntenia (Argeș, Călărași, Dâmbovița, Giurgiu, Ialomița, Prahova, Teleorman); and **MR 4** comprises South-West Oltenia (Dolj, Gorj, Mehedinți, Olt, Vâlcea) and West (Arad, Caraș-Severin, Hunedoara, Timiș)

*Figure 2*. Average triticale area (a) and yield (b) across Romania's macro-regions, 2024

The yield and quality of winter triticale are influenced by genotype, weather conditions, and their interactions, and they can be enhanced through the appropriate application of nitrogen fertilisers. The nitrogen requirement of a crop for achieving high yields is largely determined by genotype, soil type, fertility status, and moisture availability, as well as by the preceding crop, growing region, and annual weather conditions (Muntean et al., 2014). Soil characteristics, together with year-to-year climatic variability, result in significant fluctuations in crop yield (Pintilie et al., 2023). As in other cereal crops, nitrogen represents the most important agrotechnical input for achieving both high yields (Gerdzhikova et al., 2017; Bielski et al., 2020; Stefanova-Dobreva and Muhova, 2023) and high grain quality (Rajičić et al., 2023; Zhang et al., 2025). Optimal yields in intensive agricultural systems may only be attained with the application of an adequate quantity of nitrogen over the growing season, especially at periods of peak plant demand (Janušauskaite, 2013). Appropriate nitrogen availability is crucial for robust triticale growth and the development of roots, stems, and leaves (Ma et al., 2023). According to Rea et al. (2022), plants that receive sufficient nitrogen feeding are more resistant to stressors such as drought and disease pressure. Furthermore, nitrogen application may enhance triticale tolerance to frost and other adverse environmental conditions (Sułek et al., 2024). Additionally, protein accumulation in the grain is closely associated with nitrogen translocation after anthesis. Sources of grain nitrogen are generally divided into two categories: retranslocation from above-ground plant organs (70-80%) and post-anthesis uptake from the soil (20-30%) (Li et al., 2024). Consequently, the timing of supplemental fertilisation also plays an important role in achieving optimal yields that satisfy the required quality standards.

This study aimed to assess the quantitative performance of triticale germplasm in macro-region 1 of Romania under conditions of moderate nitrogen fertilisation and without phytosanitary treatments.

## MATERIAL AND METHODS

Experimental materials and methods

Field experiments were conducted at the Agricultural Research and Development Station Turda (ARDS Turda) during the 2023/2024 and 2024/2025 growing seasons, using a balanced square-grid design with six replicates. The biological material comprised 25 winter triticale genotypes, including 10 varieties (Zaraza, Utrifun, Zori, Zvelt, FDL Ascendent, Haiduc, Negoiu, Odă FD, Tulnic and Pisc) and 15 advanced breeding lines (16512T2, 16026T1, 16399T1, 16078T1, 17241T1, 17272T1, 17300T1, 17340T2, 18013T, 18017T, 18031T, 18056T, 18061T, 18339T and 07320T1).

Soil samples (0-25 cm) were analysed and classified as Phaeozem, characterised by a loamy-clay texture, a slightly acidic pH (6.09-6.15), and a humus content ranging from 3.95% to 4.50%. The total nitrogen content varied between 0.197% and 0.225%, while the levels of available phosphorus ranged from 16.8 ppm to 18.5 ppm. Additionally, potassium concentrations were found to lie between 218 ppm and 234 ppm. The soil tests were performed at OSAS (Office for Soil and Agrochemical Studies) in Arad.

The preceding crop comprised unfertilised peas. Nitrogen was applied in two split doses: 50 kg ha$^{-1}$ in autumn early (October) and 50 kg ha$^{-1}$ at the booting stage in spring, resulting in a total rate of 100 kg ha$^{-1}$. Additional nitrogen was administered in three of the six experimental replicates. No phytosanitary treatments were applied during the experiment.

Plots were harvested separately using a Wintersteiger plot combine, and grain yield was standardised to a moisture content of 14%.

Prior to harvest, 30 winter triticale plants were gathered and transported to the laboratory for analysis of grain number per spike, grain weight per spike, thousand kernel weight (TKW), test weight (TW), and harvest index (HI). Individual spikes were threshed with a Wintersteiger Micro-Batosis device. The grains collected from each spike were hand counted and weighed on a high-precision balance. The thousand-kernel weight was obtained by dividing grain weight by the number of grains and multiplying by 1,000.

Harvest index for winter triticale genotypes was calculated as:

$$HI = \frac{grain\ yield}{biological\ yield} \times 100.$$

The protein content was measured using a Perten Inframatic 9500 analyser.

Environmental conditions

Climatic conditions during the experimental period are presented in Figure 3. Meteorological data were collected from the Turda Meteorological Station (46°35′ N, 23°47′ E), situated at an altitude of 427 m above sea level.

The 2023-2024 growing season was characterised by consistently above-average temperatures, with monthly means exceeding the long-term normal by 0.8 to 7.6°C, the greatest deviation occurring in February. Sub-zero decadal mean temperatures were recorded only in January. Elevated winter temperatures substantially shortened the period of vegetative dormancy in triticale. Furthermore, above-average temperatures in February, March and April accelerated crop development, resulting in an earlier onset of the heading stage compared with previous years.

Precipitation from sowing to harvest was generally insufficient, except in November and March, which were classified as excessively wet. Approximately 20 mm of rainfall during the sowing-to-emergence period ensured uniform emergence, occurring 10 days after sowing.

Weather conditions in May and June favoured the establishment and spread of several pathogens, including *Blumeria graminis*, *Septoria* spp., *Puccinia striiformis*, and *Fusarium* spp.

The 2024-2025 growing season was characterised by marked thermal variability, with monthly mean temperature deviations from the long-term average ranging from -2°C in May to +3.9°C in March. Sub-zero decadal mean temperatures were recorded only in January and February. The first frost occurred on 20 October 2024, with a minimum temperature of 0.4°C. A subsequent cold episode between 6 and 11 April resulted in minimum air temperatures ranging from -0.7°C to -4.6°C. On 11 April 2025, these low temperatures, in conjunction with 1 mm of mixed precipitation, caused visible injury to leaf apices (scorch-like symptoms) and impeded plant growth and development. In contrast, elevated spring temperatures - during the final dekad of March, throughout April, and the first dekad of May - accelerated the onset of the heading stage, particularly in early-maturing genotypes.

Precipitation over the sowing-to-harvest period was generally deficient, except in March, May and July, which were classified as very to excessively wet. Between October 2024 and February 2025, the cumulative precipitation deficit reached 71 mm, resulting in water stress in triticale. Crop recovery commenced in the second dekad of March, when total precipitation exceeded the multi-annual average by 20.5 mm. The quantity and temporal distribution of rainfall in May and June were favourable for grain set, development and filling. In contrast, excessive precipitation in July impeded grain desiccation and delayed harvest operations.

Meteorological conditions in late May and early June favoured the establishment and spread of powdery mildew (*Blumeria graminis*), whereas yellow rust occurred only sporadically due to less favourable conditions for its development.

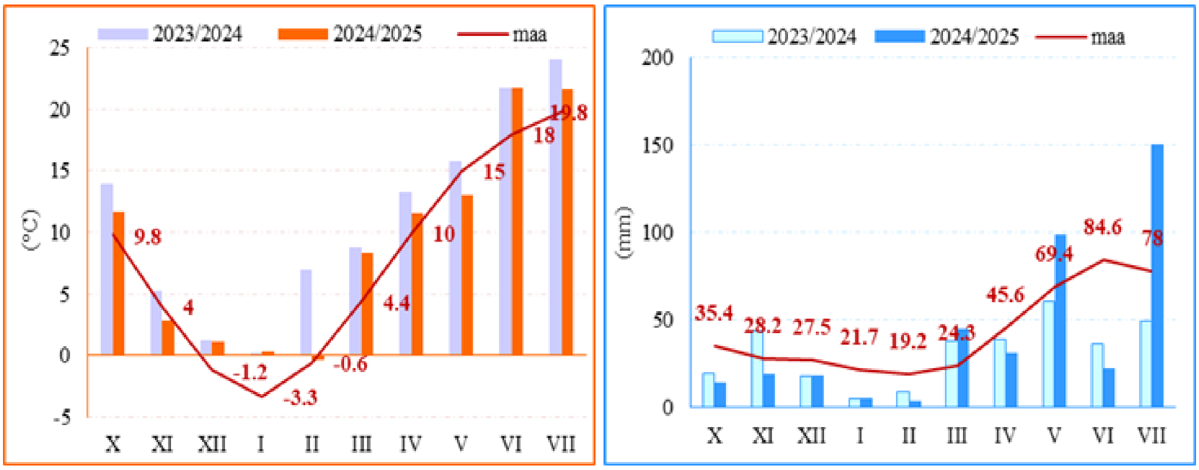



*Figure 3*. Hydrothermal conditions during the experimental period (2023/2024, 2024/2025)

<u>Statistical analysis</u>

The collected data were subjected to statistical analysis using standard analysis of variance (ANOVA), performed with PolyFact software (2020) and Microsoft Excel (2012). The PolyFact programme was used to conduct Least Significant Difference (LSD) tests at significance levels of 5%, 1%, and 0.1%. Relationships between variables (yield and protein) were assessed using the Pearson correlation coefficient, based on mean values across the two experimental years. Biplot analysis, carried out using PAST (version 4.03), was employed to identify the optimal nitrogen dose at which triticale genotypes achieve high yields under varying environmental conditions.

## RESULTS AND DISCUSSION

The two-year mean yield results, based on Duncan's ranking, indicate the superior performance of most newly improved lines, including the recently released variety Zaraza (2021). As shown in Table 1, genotypes 18061T (9,935 kg ha$^{-1}$), 18013T (9,738 kg ha$^{-1}$), and Zaraza (9,746 kg ha$^{-1}$) ranked highest, each significantly exceeding the varietal mean. In contrast, the older varieties Haiduc, Odă FD, Tulnic, and Pisc recorded the lowest yields and ranked last.

The Genotype × Year interaction highlights strong adaptability of the new genotypes to varying climatic conditions, as evidenced by their consistently high yields, particularly in 2024. Their superior production capacity is associated with multiple yield-related traits, most notably enhanced disease tolerance. Relative to the control (mean = 7,763 kg ha$^{-1}$), yield increases ranged from 470 kg ha$^{-1}$ (16399T1) to 2,071 kg ha$^{-1}$ (18061T), all of which were statistically significant. In contrast, nine of the ten triticale varieties (excluding Zaraza) yielded significantly less than the control, with reductions ranging from 909 kg ha$^{-1}$ (Zori) to 2,341 kg ha$^{-1}$ (Tulnic).

The climatic conditions of 2025 were conducive to increased yields, with the majority of genotypes exhibiting non-significant differences compared to the control (mean = 9,576 kg ha$^{-1}$). Among the 25 genotypes assessed, only FDL Ascendent, 16512T2, 16399T1, and 07320T1 considerably surpassed the control, yielding increases of 657, 498, 697, and 680 kg ha$^{-1}$, respectively. The Odă FD, Haiduc, and Pisc varieties produced significantly lower yields than the controls, with reductions of 657, 797, and 1,241 kg/ha, respectively.

As reported by Rajičić et al. (2023), meteorological conditions exerted a substantial influence on the yield components and grain quality of triticale. Favourable climatic conditions during the 2015-2016 growing season contributed to high grain yield and quality.

The response of triticale genotypes to supplementary nitrogen fertilisation was limited, with yield differences being statistically non-significant. Under the $N_{100}$ regime, compared with the control ($N_{50}$), only the genotypes Zori (+637 kg $ha^{-1}$) and 07320T1 (-729 kg $ha^{-1}$) showed significant differences in yield, as presented in Table 1.

Our results are similar to those of Abu-Altemen (2022), who evaluated seven nitrogen application rates (0-200 kg N $ha^{-1}$) on the triticale variety "*De Mantillo*" (Italian origin) and reported that nitrogen supplementation had no significant effect on shoot dry weight or grain yield under either irrigation system.

Saglam and Ustunalp (2014), evaluating six nitrogen rates (0, 6, 9, 12, 15, and 18 kg $da^{-1}$) in the triticale cultivar Karma-2000, reported that mean grain yield increased with nitrogen application up to 12 kg $da^{-1}$, beyond which no further improvement was observed. Based on experimental evidence, several authors, including, Oral (2018), Rajičić et al. (2023), and Stefanova-Dobreva and Muhova (2023), have recommended nitrogen application rates of approximately 120 kg $ha^{-1}$ to enhance both yield and quality. Excess nitrogen can reduce efficiency or cause diminishing returns. Beyond the optimum level, yield gains plateaued or declined.

The optimal nitrogen rates identified by the aforementioned researchers align with those used in our experiments (100 kg N $ha^{-1}$ plus residual nitrogen from the preceding pea crop). However, these findings contrast with those reported by Fatimah (2025), which suggested that increasing the nitrogen treatment enhanced yield components and total grain production, with peak mean values recorded at 200 kg N $ha^{-1}$ ($N_3$).

Zhang et al. (2025) showed that nitrogen fertilisation increased biomass, photosynthesis, and protein synthesis by improving stress tolerance and metabolic activity, explaining yield increases at the physiological level.

The genotype-environment interaction (Figure 4a) was investigated using principal component analysis (PC1), which accounted for 91.467% of the variation, indicating that genotypes closer to the biplot's PC2 axis, including Zaraza, 18061T, 18013T, 18031T, 18017T, and 17241T1, were more stable and less sensitive to environmental impacts. In contrast, genotypes located further distant from the origin showed greater sensitivity and interaction effects (Wodebo et al., 2023; Chețan et al., 2024). The interaction between genotype and weather conditions resulted in distinct genotypic responses, with FDL Ascendent, Utrifun, 16512T2, 16399T1, 07320T1, and 17340T2 exhibiting higher yields under the environmental conditions of 2025. Pisc, Haiduc, and Odă FD exhibited the lowest yields in both years. The 16026T1 genotype consistently produced yields comparable to the experimental mean.

The biplot analysis depicted in Figure 4b explains the variance and indicates that most genotypes are minimally affected by the additional nitrogen dose ($N_{100}$), suggesting that applying a higher nitrogen rate is unnecessary. The genotypes Haiduc, Odă FD, Tulnic, and Pisc demonstrate a low yield potential. Zori was the sole genotype that demonstrated a notable yield enhancement in response to the $N_{100}$ treatment while remaining below the average of the varieties. Of all the genotypes, only the 07320T1 breeding line displayed a significantly superior yield under the $N_{50}$ fertilisation condition. Genotypes 18061T, Zaraza, 18013T, 17241T1, 18017T, and 18031T produced the highest yields at both nitrogen rates ($N_{50}$, $N_{100}$), confirming the genetic basis of their yield potential.

Table 1. Analysis of the yields (kg ha$^{-1}$) obtained according to the experimental factors

| Triticale Genotypes | Duncan's ranking | | G × Y | | | | Y × G | | G × F | | | | F × G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2024 | | 2025 | | 2024 | 2025 | $N_{50}$ | | $N_{100}$ | | $N_{100}$ - $N_{50}$ |
| Zaraza | 9746 | ab | 9670 | *** | 9821 | ns | ns | ns | 9563 | *** | 9928 | *** | ns |
| Utrifun | 8176 | hi | 6401 | °°° | 9951 | ns | °° | ** | 7999 | ° | 8353 | ns | ns |
| Zori | 8165 | hi | 6854 | °°° | 9476 | ns | ° | * | 7846 | °° | 8484 | ns | * |
| Zvelt | 7944 | ij | 6648 | °°° | 9241 | ns | ° | * | 7751 | °°° | 8137 | °° | ns |
| FDL Ascendent | 8522 | fgh | 6811 | °°° | 10232 | ** | °° | ** | 8290 | ns | 8753 | ns | ns |
| Haiduc | 7454 | k | 6129 | °°° | 8779 | °°° | ° | * | 7670 | °°° | 7238 | °°° | ns |
| Negoiu | 7804 | j | 6446 | °°° | 9162 | ns | ° | * | 7504 | °°° | 8104 | °° | ns |
| Odă FD | 7418 | k | 5895 | °°° | 8941 | °° | ° | * | 7353 | °°° | 7484 | °°° | ns |
| Tulnic | 7286 | k | 5422 | °°° | 9150 | ns | °° | ** | 7163 | °°° | 7410 | °°° | ns |
| Pisc | 7385 | k | 6435 | °°° | 8335 | °°° | ° | * | 7226 | °°° | 7543 | °°° | ns |
| 16512T2 | 9302 | cd | 8531 | ** | 10074 | * | ns | ns | 9137 | * | 9468 | ** | ns |
| 16026T1 | 8493 | gh | 7368 | ns | 9619 | ns | ° | * | 8587 | ns | 8400 | ns | ns |
| 16399T1 | 9253 | cd | 8233 | * | 10273 | ** | ° | * | 9177 | ** | 9329 | * | ns |
| 16078T1 | 8988 | de | 8362 | * | 9615 | ns | ns | ns | 8994 | ns | 8982 | ns | ns |
| 17241T1 | 9409 | bc | 9400 | *** | 9418 | ns | ns | ns | 9401 | *** | 9417 | ** | ns |
| 17272T1 | 8935 | de | 8212 | ns | 9658 | ns | ns | ns | 8750 | ns | 9120 | ns | ns |
| 17300T1 | 8568 | fg | 7589 | ns | 9547 | ns | ° | * | 8489 | ns | 8647 | ns | ns |
| 17340T2 | 8193 | hi | 6694 | °°° | 9692 | ns | ° | * | 8147 | ns | 8240 | ° | ns |
| 18013T | 9738 | ab | 9498 | *** | 9978 | ns | ns | ns | 9679 | *** | 9797 | *** | ns |
| 18017T | 9411 | bc | 9275 | *** | 9546 | ns | ns | ns | 9399 | *** | 9422 | ** | ns |
| 18031T | 9544 | bc | 9680 | *** | 9409 | ns | ns | ns | 9296 | ** | 9793 | *** | ns |
| 18056T | 9250 | cd | 8638 | *** | 9862 | ns | ns | ns | 9095 | * | 9405 | ** | ns |
| 18061T | 9935 | a | 9835 | *** | 10035 | ns | ns | ns | 9686 | *** | 10184 | *** | ns |
| 18339T | 8859 | ef | 8395 | ** | 9323 | ns | ns | ns | 8671 | ns | 9048 | ns | ns |
| 07320T1 | 8958 | de | 7660 | ns | 10256 | ** | ° | * | 9322 | ** | 8593 | ns | ° |
| **mean** | **8669** | Ct. | **7763** | Ct. | **9576** | Ct. | - | - | **8568** | **Ct.** | **8771** | **Ct.** | - |
| LSD 5% | 326 | | 461 | | | | 832 | | 461 | | | | 628 |

Means with different letters are statistically significant at P value equal or less than 0.05 using LSD test. Different means with similar letters are statistically non-significant. ns = non-significant. *, ° = $p < 0.05$; **, °° = $p < 0.01$ and ***, °°° = $p < 0.001$.

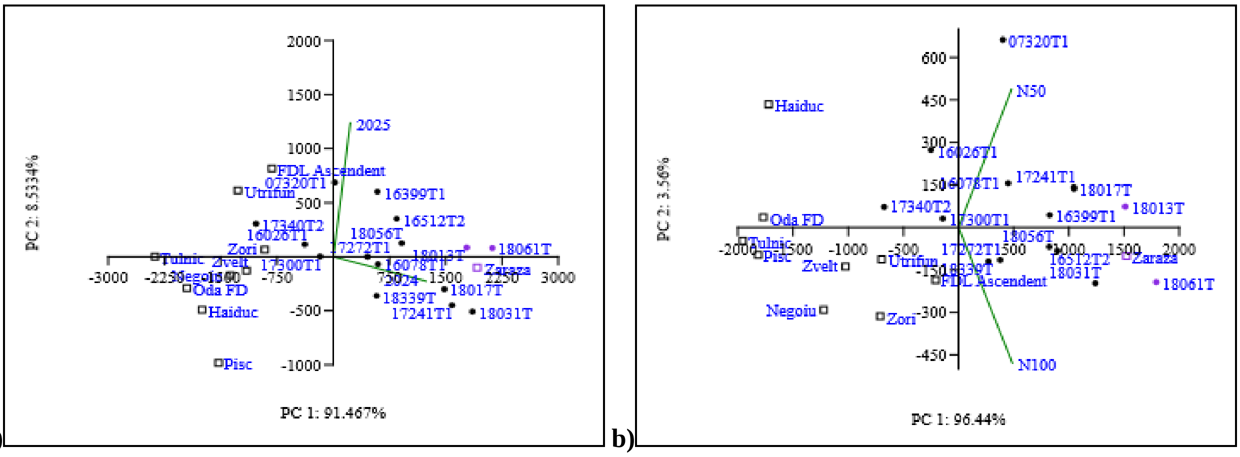



*Figure 4*. Graphics of Past 4.03.exe biplot analysis of grain yield of winter triticale genotypes in terms of determining: a) genotype × weather conditions interaction; b) which is the best amount of nitrogen fertilizer for what triticale genotype

Figure 5 illustrates the outcomes of the three-way interaction (G × Y × F) concerning the yield of winter triticale (kg ha$^{-1}$). While the average annual yields for both fertilisation treatments were comparable (7,750 kg ha$^{-1}$ for $N_{50}$ and 7,777 kg ha$^{-1}$ for $N_{100}$ in 2024; 9,386 kg ha$^{-1}$ for $N_{50}$ and 9,765 kg ha$^{-1}$ for $N_{100}$ in 2025, serving as the control), notable varietal disparities were evident in their adaptability to environmental conditions and nitrogen-use efficiency, suggesting that particular varieties may exhibit superior performance under specific circumstances or varying nitrogen levels. In 2024, with extra fertilisation, the 18031T and 18061T winter triticale genotypes outperformed the control (7,777 kg ha$^{-1}$) by 2,163 kg ha$^{-1}$ and 2,382 kg ha$^{-1}$, respectively. These differences were statistically highly significant. Their yields surpassed those of the Zaraza variety by 167 kg ha$^{-1}$ and 386 kg ha$^{-1}$, respectively.

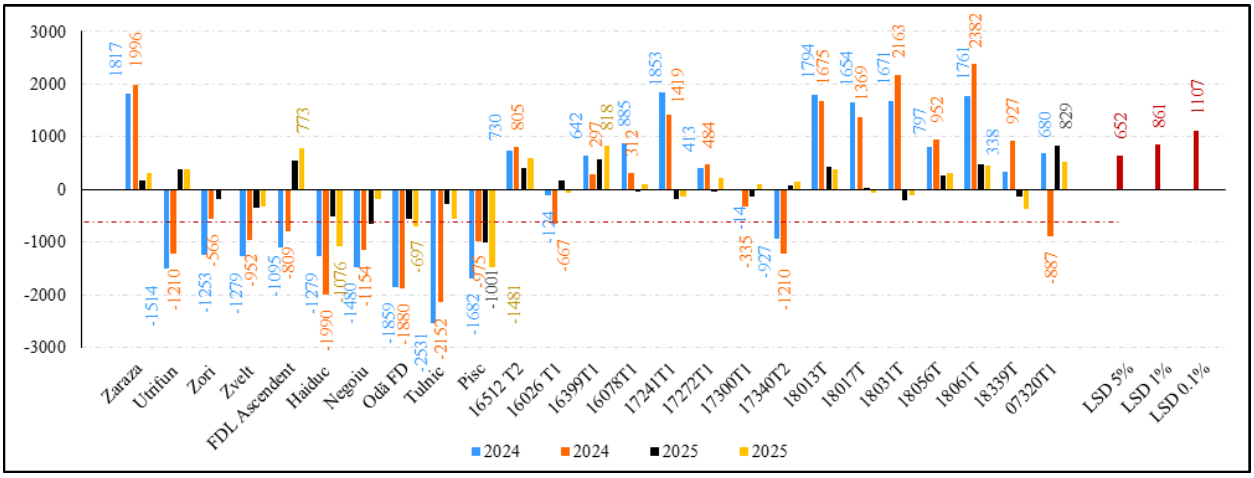



*Figure 5.* The result of the three-way interaction (G × Y × F) regarding the yield of winter triticale (kg ha$^{-1}$)

The thousand kernel weight (TKW) is primarily determined by genotype and environmental circumstances, including water availability and temperature during grain formation and filling. It is also influenced by disease and insect outbreaks, including *Fusarium*, *Septoria*, *Puccinia*, cereal bugs, and thrips. TKW, an essential indicator of grain quality, is notably affected by nitrogen fertilisation (Protic et al., 2007a; Wu et al., 2018). In this study, the annual mean TKW was 40.32 g in 2024 and 47.92 g in 2025, reflecting the interaction between triticale genotypes and environmental circumstances. The mean TKW for all treatments ranged from 38.10 to 50.42 g (Table 2). The genotypes with the highest TKW values were 18061T (50.42 g), 18017T (49.59 g), and 18339T (48.97 g). Duncan's test revealed that the lowest-ranked genotypes were Zori, FDL Ascendent, 16399T1, and 16026T1, with TKW values ranging from 38 to 40 g. The genotypes Utrifun, 17300T1, 18031T, 18061T, and 18339T consistently exceeded the control value, defined as the mean of all genotypes, in both experimental years. Genotypic responses to supplemental fertilisation varied considerably. Compared with the control treatment ($N_{50}$), genotype 18013T was the only one that showed no significant change in TKW following additional nitrogen application. Increases in TKW greater than 3 g in response to supplemental fertilisation were observed for the following genotypes: Odă FD (+3.03 g), 18339T (+3.63 g), Zvelt (+4.95 g), 17272T1 (+5.53 g), and Pisc (+7.07 g).

Test weight (hectolitre weight) is an important cereal quality trait reflects grain density and is widely used in grading and market valuation. It is included in most cereal grading standards and can therefore influence the price received by farmers (Marinciu et al., 2021). Test weight (TW) is influenced by several factors, including variations in grain moisture at harvest (Joshi et al., 2024), the presence of impurities (Manley et al., 2009), and grain size, shape, and density (Protic et al., 2007b). Soil type, grain surface characteristics, weather conditions during grain filling, and disease or pest infestation also contribute substantially to TW variation (Muntean et al., 2014; Marinciu et al., 2021), which can ultimately affect the overall quality and marketability of the grain produced by farmers.

The mean test weight recorded across the experiment was 71.61 kg hL$^{-1}$. Genotype-dependent variation was observed, with average values ranging from 65.67 kg hL$^{-1}$ in Haiduc to 76.02 kg hL$^{-1}$ in line 18056T. The influence of contrasting climatic conditions between the two experimental years was also evident, as reflected by lower mean test weight in 2024 (69.30 kg hL$^{-1}$) compared with 2025 (73.92 kg hL$^{-1}$). The results obtained in 2024 suggest that, under unfavourable environmental conditions, older genotypes exhibited reduced grain-filling capacity, as indicated by test weight values below 70 kg hL$^{-1}$. Across both experimental years, several genotypes consistently demonstrated significantly higher test weight values than the overall mean, including Zaraza, 17241T1, 17272T1, 18017T, 18031T, 18056T, 18339T, and 07320T1 (Table 2).

Nitrogen fertilisation, which is usually given between the tillering and booting stages, is meant to compensate for nutrient deficits that occur during the growing season. Such shortcomings may be caused by inadequate agronomic techniques, severe weather circumstances (including drought), or increased plant growth. Alaru et al. (2004) revealed that applying higher nitrogen rates at the late EC47 stage significantly boosted test weight and grain protein content while decreasing stem height. In the present study, supplemental nitrogen fertilisation applied at the booting stage, in interaction with prevailing climatic conditions, enhanced grain filling in the majority of genotypes. Differences relative to the control treatment ($N_{50}$) ranged from 0.33 kg $hL^{-1}$ in line 16512T2 to 1.97 kg $hL^{-1}$ in line 18056T and were statistically significant. Only four triticale genotypes exhibited significantly lower test weight values compared with the control, namely FDL Ascendent (-2.47 kg $hL^{-1}$), Haiduc (-4.00 kg $hL^{-1}$), Negoiu (-1.37 kg $hL^{-1}$), and 07320T1 (-0.17 kg $hL^{-1}$).

Table 2. Analysis of the thousand kernel weight (g) and test weight (kg $hl^{-1}$) obtained according to the experimental factors

| Triticale Genotypes | Thousand kernel weight (g) | | | | | | | | | | Test weight (kg $hl^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duncan's ranking | | G × Y | | | | F × G | | | | Duncan's ranking | | G × Y | | | | F × G | | | |
| | | | 2024 | | 2025 | | $N_{50}$ | $N_{100}$ | | | | | 2024 | | 2025 | | $N_{50}$ | $N_{100}$ | | |
| Zaraza | 46.22 | i | 46.46 | *** | 45.98 | °°° | 45.77 | 46.67 | *** | | 75.46 | c | 75.9 | *** | 75.02 | *** | 74.92 | 76 | *** | |
| Utrifun | 46.7 | g | 44.07 | *** | 49.34 | *** | 51.02 | 42.39 | °°° | | 69.79 | r | 65.95 | °°° | 73.63 | °°° | 69.52 | 70.07 | *** | |
| Zori | 38.1 | t | 32.62 | °°° | 43.59 | °°° | 39.45 | 36.76 | °°° | | 68.39 | v | 63.55 | °°° | 73.23 | °°° | 68.13 | 68.65 | *** | |
| Zvelt | 42.82 | o | 36.74 | °°° | 48.9 | *** | 40.35 | 45.29 | *** | | 70.73 | n | 67.15 | °°° | 74.32 | *** | 70.35 | 71.12 | *** | |
| FDL Ascendent | *38.13* | t | 30.24 | °°° | 46.03 | °°° | 39.2 | 37.07 | °°° | | 68.63 | t | 63.3 | °°° | 73.97 | ns | 69.87 | 67.4 | °°° | |
| Haiduc | 43.83 | m | 32.53 | °°° | 55.14 | *** | 46.49 | 41.18 | °°° | | 65.67 | w | 59.35 | °°° | 71.98 | °°° | 67.67 | 63.67 | °°° | |
| Negoiu | 44.89 | k | 33.18 | °°° | 56.61 | *** | 46.19 | 43.59 | °°° | | 65.73 | w | 59.85 | °°° | 71.62 | °°° | 66.42 | 65.05 | °°° | |
| Odă FD | 40.85 | r | 32.01 | °°° | 49.69 | *** | 39.33 | 42.36 | *** | | 68.49 | u | 64.9 | °°° | 72.08 | °°° | 68.15 | 68.83 | *** | |
| Tulnic | 40.78 | r | 34.05 | °°° | 47.52 | °°° | 39.4 | 42.17 | *** | | 69.99 | q | 65.1 | °°° | 74.88 | *** | 69.95 | 70.03 | ns | |
| Pisc | 43.19 | n | 36.67 | °°° | 49.71 | *** | 39.65 | 46.72 | *** | | 70.25 | p | 67.9 | °°° | 72.6 | °°° | 69.95 | 70.55 | *** | |
| 16512T2 | 44.99 | j | 42.39 | *** | 47.6 | °°° | 46.41 | 43.57 | °°° | | 71.72 | m | 70 | *** | 73.43 | °°° | 71.55 | 71.88 | *** | |
| 16026T1 | 39.65 | s | 34.77 | °°° | 44.54 | °°° | 40.49 | 38.81 | °°° | | 69.6 | s | 66.6 | °°° | 72.6 | °°° | 69.17 | 70.03 | *** | |
| 16399T1 | 39.57 | s | 35.75 | °°° | 43.4 | °°° | 39.2 | 39.94 | *** | | 70.41 | o | 67.75 | °°° | 73.07 | °°° | 70.02 | 70.8 | *** | |
| 16078T1 | 42.18 | p | 37.12 | °°° | 47.25 | °°° | 40.73 | 43.64 | *** | | 72.38 | k | 71.4 | *** | 73.35 | °°° | 72 | 72.75 | *** | |
| 17241T1 | 46.55 | h | 46.05 | *** | 47.06 | °°° | 45.83 | 47.28 | *** | | 75.22 | d | 74.25 | *** | 76.18 | *** | 74.75 | 75.68 | *** | |
| 17272T1 | 44.06 | l | 45.19 | *** | 42.94 | °°° | 41.3 | 46.83 | *** | | 74.71 | e | 74.05 | *** | 75.37 | *** | 73.78 | 75.63 | *** | |
| 17300T1 | 47.22 | f | 45.01 | *** | 49.43 | *** | 48.59 | 45.85 | °°° | | 72.14 | l | 69.35 | ns | 74.93 | *** | 71.35 | 72.93 | *** | |
| 17340T2 | 41.75 | q | 36.37 | °°° | 47.13 | °°° | 43.61 | 39.89 | °°° | | 69.99 | q | 67.45 | °°° | 72.53 | °°° | 69.45 | 70.53 | *** | |
| 18013T | 47.57 | e | 47.24 | *** | 47.91 | ns | 47.51 | 47.63 | ns | | 73.75 | i | 73.45 | *** | 74.05 | * | 73.05 | 74.45 | *** | |
| 18017T | 49.59 | b | 52.01 | *** | 47.17 | °°° | 49.13 | 50.05 | *** | | 75.84 | b | 76.2 | *** | 75.48 | *** | 75.37 | 76.32 | *** | |
| 18031T | 48.53 | d | 46.82 | *** | 50.23 | *** | 47.64 | 49.42 | *** | | 74.63 | f | 74.65 | *** | 74.6 | *** | 74.35 | 74.9 | *** | |
| 18056T | 44.8 | k | 42.18 | *** | 47.43 | °°° | 45.37 | 44.24 | °°° | | 76.02 | a | 75.5 | *** | 76.53 | *** | 75.03 | 77 | *** | |
| 18061T | *50.42* | a | 50.99 | *** | 49.85 | *** | 50.95 | 49.89 | °°° | | 73.88 | h | 73.85 | *** | 73.9 | ns | 73.38 | 74.37 | *** | |
| 18339T | 48.97 | c | 48.22 | *** | 49.72 | *** | 47.16 | 50.79 | *** | | 74.23 | g | 74.25 | *** | 74.2 | *** | 73.83 | 74.62 | *** | |
| 07320T1 | 41.75 | q | 39.49 | °°° | 44.01 | °°° | 40.42 | 43.08 | *** | | 72.67 | j | 70.9 | *** | 74.43 | *** | 72.75 | 72.58 | °° | |
| **mean** | **44.12** | Ct. | **40.32** | Ct. | **47.92** | Ct. | Ct. | - | | | **71.61** | Ct. | **69.3** | Ct. | **73.92** | Ct. | Ct. | - | | |

Means with different letters are statistically significant at P value equal or less than 0.05 using LSD test. Different means with similar letters are statistically non-significant. ns = non-significant. *, ° = $p < 0.05$; **, °° = $p < 0.01$ and ***, °°° = $p < 0.001$.

Table 3 presents data on the number and weight of grains per spike. The mean number of grains per spike was 47.93, with values ranging from 42.60 in Pisc to 57.42 in line 16512T2. Variation between experimental years was evident, with an average of 43.68 grains per spike recorded in 2024, representing a reduction of 8.5 grains per spike compared with 2025. Several genotypes, including Haiduc, 16512T2, 16399T1, 17241T1, 17272T1, 17300T1, and 07320T1, consistently produced a significantly higher number of grains per spike than the control across both experimental years. A comparison between years indicates that, in 2025, certain genotypes exhibited a markedly greater number of grains per spike relative to 2024, namely Utrifun (+13.51), Zvelt (+12.38), FDL Ascendent (+14.35), Odă FD (+14.74), 16512T2 (+18.23), 16026T1

(+11.56), 16399T1 (+18.65), 17272T1 (+13.20), and 17300T1 (+13.18). In contrast, genotypes 18017T, 18031T, and 07320T1 demonstrated a relatively stable number of grains per spike, showing no significant variation in response to climatic conditions.

Supplementary nitrogen fertilisation elicited a positive response in only a limited number of genotypes, with a significant increase in the number of grains per spike observed in 17340T2 (+4.83 grains spike$^{-1}$), Negoiu (+8.19 grains spike$^{-1}$), and 18339T (+11.46 grains spike$^{-1}$). In contrast, the cultivar Zori exhibited no statistically significant differences in this trait. For the remaining genotypes, supplementary nitrogen application resulted in varying degrees of reduction in the number of grains per spike. Notable decreases were recorded in Pisc (-8.20 grains spike$^{-1}$), 18061T (-9.00 grains spike$^{-1}$), 18056T (-12.00 grains spike$^{-1}$), and Tulnic (-14.00 grains spike$^{-1}$).

The mean grain weight per spike was 2.13 g. Duncan's multiple range test identified genotypes 16512T2 (2.61 g) and 17300T1 (2.58 g) as having the highest values, whereas Tulnic (1.87 g) and Pisc (1.84 g) recorded the lowest. In 2025, the mean grain weight per spike increased by 0.73 g relative to the previous year, indicating a pronounced environmental effect. Genotypic responses varied considerably between the two experimental years. Only three genotypes (namely 16512T2, 17300T1, and 17241T1) consistently demonstrated grain weight per spike significantly higher than the overall mean. In contrast, Zori, FDL Ascendent, Tulnic, Pisc, 16026T1, 16078T1, and 17340T2 exhibited significantly lower values than the control across both years.

A positive effect of supplemental fertilisation on grain weight per spike was observed in a limited number of genotypes, with increases ranging from 0.2 g (16078T1 and 17241T1) to 0.72 g (18339T1). Conversely, several genotypes exhibited reductions following supplemental fertilisation, with decreases ranging from 0.07 g (18031T) to 0.94 g (Haiduc).

*Table 3.* Analysis of the number of grains per spike and weight of grains per spike (g) obtained according to the experimental factors

| Triticale Genotypes | Number of grains per spike | | | | | | | | | Weight of grains per spike (g) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duncan's ranking | | G × Y | | | | F × G | | | Duncan's ranking | | G × Y | | | | F × G | | |
| | | | 2024 | | 2025 | | $N_{50}$ | $N_{100}$ | | | | 2024 | | 2025 | | $N_{50}$ | $N_{100}$ | |
| Zaraza | 45.79 | m | 41.54 | °°° | 50.05 | °°° | 45.45 | 46.13 | *** | 2.11 | h | 1.93 | *** | 2.3 | °°° | 2.08 | 2.15 | * |
| Utrifun | 43.43 | u | 36.68 | °°° | 50.19 | °°° | 43.62 | 43.25 | °°° | 2.06 | i | 1.65 | °°° | 2.47 | ns | 2.22 | 1.9 | °°° |
| Zori | 49.6 | f | 47.61 | *** | 51.59 | °°° | 49.64 | 49.55 | ns | 1.91 | m | 1.57 | °°° | 2.25 | °°° | 1.94 | 1.88 | ° |
| Zvelt | 44.97 | r | 38.78 | °°° | 51.16 | °°° | 44.82 | 45.12 | *** | 1.97 | kl | 1.43 | °°° | 2.51 | ns | 1.84 | 2.1 | *** |
| FDL Ascendent | 44.9 | r | 37.73 | °°° | 52.08 | ° | 45.4 | 44.41 | °°° | 1.77 | o | 1.15 | °°° | 2.4 | °° | 1.8 | 1.74 | ° |
| Haiduc | 48.55 | h | 43.96 | *** | 53.14 | *** | 56.11 | 40.99 | °°° | 2.19 | fg | 1.46 | °°° | 2.93 | *** | 2.67 | 1.72 | °°° |
| Negoiu | 44.13 | t | 40.18 | °°° | 48.07 | °°° | 40.03 | 48.22 | *** | 2.03 | ij | 1.33 | °°° | 2.72 | *** | 1.86 | 2.19 | *** |
| Odă FD | 45.32 | q | 37.95 | °°° | 52.69 | *** | 46.46 | 44.18 | °°° | 1.91 | m | 1.21 | °°° | 2.62 | *** | 1.87 | 1.95 | * |
| Tulnic | 45.39 | p | 42.48 | °°° | 48.31 | °°° | 52.42 | 38.37 | °°° | 1.87 | n | 1.44 | °°° | 2.29 | °°° | 2.05 | 1.68 | °°° |
| Pisc | 42.6 | v | 40.44 | °°° | 44.75 | °°° | 46.71 | 38.49 | °°° | 1.84 | n | 1.46 | °°° | 2.22 | °°° | 1.86 | 1.82 | ns |
| 16512T2 | 57.42 | a | 48.31 | *** | 66.54 | *** | 60.77 | 54.08 | °°° | 2.61 | a | 2.08 | *** | 3.15 | *** | 2.82 | 2.41 | °°° |
| 16026T1 | 48.69 | g | 42.96 | °°° | 54.52 | *** | 48.55 | 48.82 | *** | 1.96 | lm | 1.49 | °°° | 2.42 | ° | 2 | 1.92 | °° |
| 16399T1 | 55.3 | b | 45.98 | *** | 64.63 | *** | 58.57 | 52.04 | °°° | 2.22 | ef | 1.65 | °°° | 2.8 | *** | 2.31 | 2.14 | °°° |
| 16078T1 | 47.08 | k | 43.79 | * | 50.38 | °°° | 46.48 | 47.69 | *** | 2 | jk | 1.63 | °°° | 2.38 | °°° | 1.91 | 2.1 | *** |
| 17241T1 | 51.2 | e | 48.09 | *** | 54.31 | *** | 49.95 | 52.45 | *** | 2.39 | b | 2.22 | *** | 2.56 | * | 2.3 | 2.48 | *** |
| 17272T1 | 51.15 | e | 44.55 | *** | 57.75 | *** | 51.86 | 50.45 | °°° | 2.28 | cd | 2.02 | *** | 2.56 | ns | 2.15 | 2.41 | *** |
| 17300T1 | 54.34 | c | 47.75 | *** | 60.93 | *** | 57.87 | 50.82 | °°° | 2.58 | a | 2.16 | *** | 3.01 | *** | 2.81 | 2.35 | °°° |
| 17340T2 | 45.7 | n | 41.15 | °°° | 50.26 | °°° | 43.29 | 48.12 | *** | 1.93 | lm | 1.49 | °°° | 2.37 | °°° | 1.92 | 1.94 | ns |
| 18013T | 48.33 | i | 45.02 | *** | 51.65 | °°° | 52.1 | 44.57 | °°° | 2.3 | c | 2.14 | *** | 2.47 | ns | 2.47 | 2.13 | °°° |
| 18017T | 47.1 | k | 47.91 | *** | 46.29 | °°° | 50.98 | 43.21 | °°° | 2.32 | c | 2.46 | *** | 2.18 | °°° | 2.48 | 2.16 | °°° |
| 18031T | 44.37 | s | 44.7 | *** | 44.04 | °°° | 46.13 | 42.61 | °°° | 2.15 | h | 2.09 | *** | 2.22 | °°° | 2.19 | 2.11 | ° |
| 18056T | 47.8 | j | 43.16 | °°° | 52.43 | *** | 53.81 | 41.79 | °°° | 2.16 | gh | 1.83 | ns | 2.49 | ns | 2.45 | 1.87 | °°° |
| 18061T | 45.54 | o | 44 | *** | 47.08 | °°° | 50.08 | 41.01 | °°° | 2.31 | c | 2.27 | *** | 2.35 | °°° | 2.57 | 2.06 | °°° |
| 18339T | 45.9 | l | 44.84 | *** | 46.96 | °°° | 40.17 | 51.63 | *** | 2.25 | de | 2.17 | *** | 2.34 | °°° | 1.89 | 2.62 | *** |
| 07320T1 | 53.71 | d | 52.55 | *** | 54.87 | *** | 50.84 | 56.57 | *** | 2.25 | de | 2.08 | *** | 2.43 | ° | 2.05 | 2.45 | *** |
| **mean** | **47.93** | Ct. | **43.68** | Ct. | **52.18** | Ct. | Ct. | - | | **2.13** | Ct. | **1.77** | Ct. | **2.50** | Ct. | Ct. | - | |

Means with different letters are statistically significant at P value equal or less than 0.05 using LSD test. Different means with similar letters are statistically non-significant. ns = non-significant. *, ° = $p < 0.05$; **, °° = $p < 0.01$ and ***, °°° = $p < 0.001$.

The harvest index represents the weight of a harvested product as a percentage of the total weight of a crop's plants. It is influenced by interactions among genotypes, environmental factors, and crop management practices. Typically, the harvest index is a critical parameter in plant breeding programmes and is utilised to identify the most suitable genotype. To understand how a crop responds to different environments and climatic variations, it is essential to consider the concept of the harvest index. Hay (2008) noted that the harvest index values for contemporary varieties of most extensively grown grain crops typically range from 0.4 to 0.6. Generally, consistent individual grain weight and increased grain population density have led to enhancements in the harvest index. Considering the interaction of experimental factors, the harvest index ranged between 0.34 and 0.36 in 2024 and between 0.43 and 0.45 in 2025. Despite the limiting influence of environmental conditions on the expression of yield potential, Figure 6 highlights several genotypes that maintained consistently high and relatively stable mean harvest index values: Zaraza (HI: 0.405 in 2024; 0.43 in 2025), 18061T (0.425; 0.44), 18031T (0.415; 0.435), 17241T1 (0.41; 0.45), 18013T (0.385; 0.455), and 18056T (0.395; 0.435).

Under both fertilisation regimes, a strong negative relationship between yield and grain quality was observed, as confirmed by the Pearson correlation coefficient (Figure 7). Increasing the nitrogen rate intensified this antagonistic relationship between yield and protein content. Based on the mean values, 8,771 kg ha$^{-1}$ and 11.1% protein for the $N_{100}$ treatment, and 8,568 kg ha$^{-1}$ and 9.8% protein for the $N_{50}$ treatment, it can be inferred that a significant proportion of the nitrogen applied during the grain-filling stage plays a crucial role in enhancing grain quality.

Genotypes with both high yield and favourable protein content were identified in quadrant IV, as well as in quadrant III (on or just below the regression line), including 18013T, 18031T, 18017T, 18056T, 17241T1, and Zaraza. Notably, the triticale line 18061T demonstrated an efficient utilisation of additional nitrogen, resulting in enhanced yield performance.

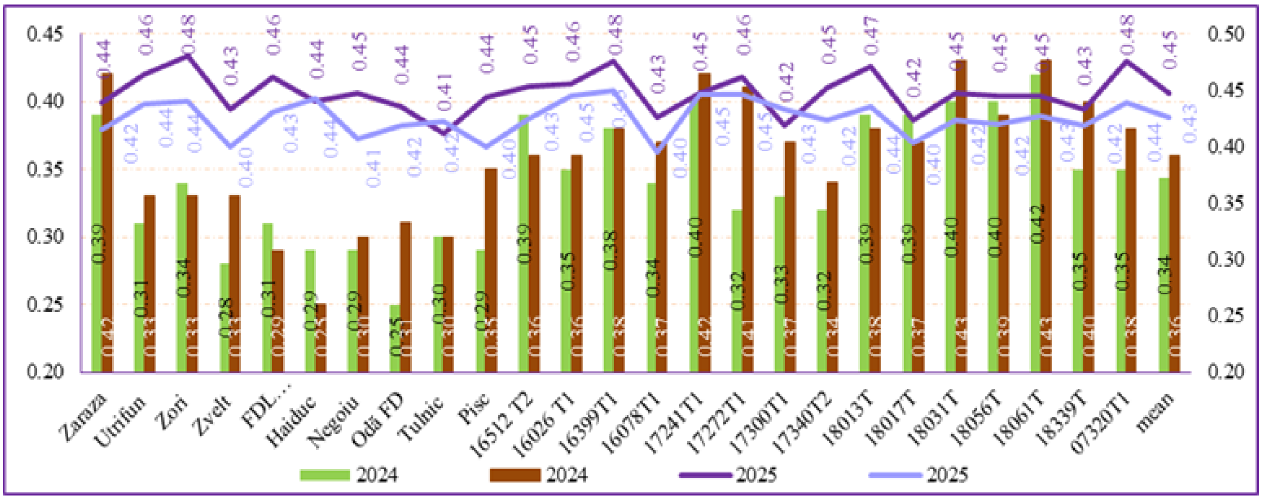



*Figure 6*. Variation in the harvest index according to the experimental factors

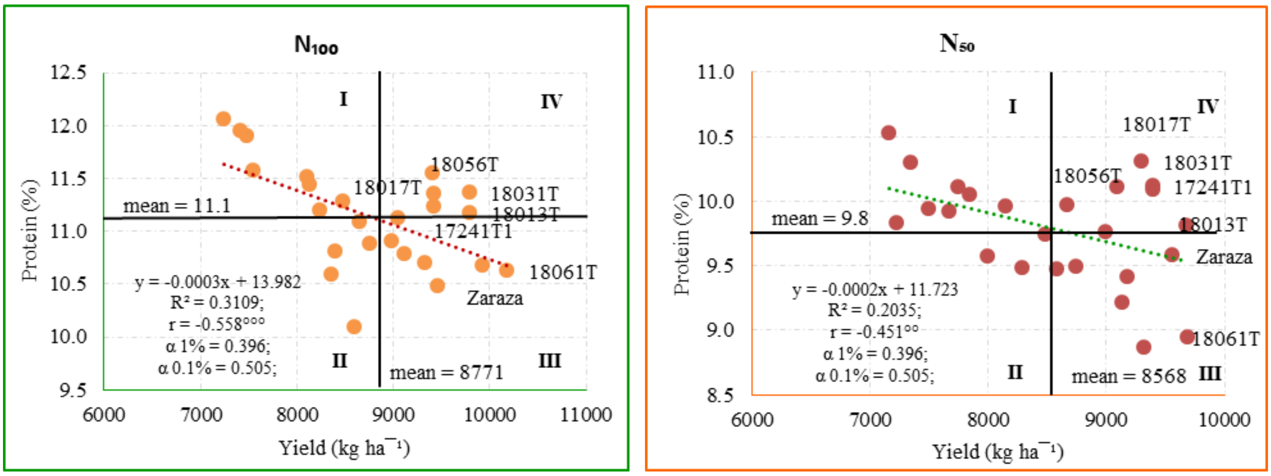



*Figure 7*. Relationship between grain yield and protein concentration according to the N rate

## CONCLUSIONS

Despite the absence of phytosanitary treatments, modest nitrogen application, and weather conditions conducive to disease development (particularly in 2024, including *Blumeria* spp., *Puccinia* spp., and *Fusarium* spp.), winter triticale performed favourably in macro-region 1.

The genotypes 18061T, Zaraza, 18013T, 17241T1, 18017T, and 18031T produced the highest yields under both nitrogen rates ($N_{50}$, $N_{100}$), confirming the genetic control of yield potential. The analysis of the relationship between yield and protein content suggests that, with supplementary nitrogen application during the booting stage (a standard practice in the unit's cereal breeding field), these genotypes are capable of achieving both high yield and quality. In addition, harvest values indicate that, despite environmental constraints affecting yield potential, these genotypes maintained relatively stable productivity across conditions, highlighting their good yield stability and adaptability.

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