

VARIABILITY OF QUANTITATIVE TRAITS IN WINTER TRITICALE IN THE CENTRAL REGION OF BELARUS

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The article presents the results of a long-term study of quantitative traits in winter triticale varieties and accessions grown in the soil/climatic conditions of the central region of Belarus using conventional and intensive cultivation technologies. The effects of the intensification level on the yield, performance constituents and triticale grain quality are described.

Key words: *winter triticale, cultivation technology, yield, quantitative traits, variability*

Introduction. High yields in various soil/climatic conditions are the main factor in the competitiveness of triticale as a grain fodder crop. In Belarus, the crop is represented mainly by the more productive winter form, as evidenced by sown area and number of released varieties [1, 2]. In 2020, the triticale crops on the territory of the Republic occupied 451,800 hectares, and winter triticale accounted for 438,000 hectares (96.7%) [3]. Of the 32 triticale varieties included in the State Register of the Republic of Belarus (2020), 23 domestic (10) and foreign (13) varieties are winter ones. In addition to domestic varieties, eight Polish, three German, one Ukrainian and one French winter varieties are allowed for cultivation on the territory of the Republic, with different areas of admissibility. The dynamic evolutionary formation of the triticale crop is associated with significant genotypic and modification variabilities of quantitative traits and a broad morphogenesis affected by biotic and abiotic factors [4, 5].

Our **purpose** was to assess the variability of quantitative traits in winter triticale grown by conventional and intensive cultivation technologies in Belarus.

Materials and methods. Winter hexaploid triticale (*X Triticosecale* Wittm. & A. Camus, $2n = 42$) varieties and promising accessions bred in Belarus and other countries (Poland, Ukraine, Russia) from a competitive variety trial nursery were studied. Thirty accessions were tested annually in the experimental fields of the Research and Practical Centre of the National Academy of Sciences of Belarus for Arable Farming using conventional and intensive cultivation technologies in accordance with the industry regulations [6]. Upon intensive cultivation, additional doses of nitrogen fertilizers, trace elements (Cu, Mn), growth regulators and fungicides were applied. The plot area was 10 m²; the replication number was three; the design was randomized; the seeding rate was 4.5 million viable seeds per hectare; the observation period was in 2011–2020.

We determined the yield, the grain number and weight from the main spike, test weight, and 1000-grain weight. The contents of crude protein, gluten and starch in grain were determined by near-infrared spectroscopy: the standard error of calibration and the coefficient of determination for crude protein (as total nitrogen) were 0.05 and 0.98, respectively; for gluten – 1.36 and 0.91, respectively; and for crude starch – 1.15 and 0.87, respectively. Data were statistically processed, as Dospekhov described [7].

The weather factors influencing the yield were not uniform during the observation period. Five out of ten years can be categorized as unfavorable ones, through the lens of fulfilling the performance potential. In 2011, 2013 and 2019, a severe (5–7 points) massive snow mold-induced damage to winter triticale fields was the main factor limiting the yield. The water deficit negatively affected the triticale yield in 2015 and, especially, in 2018, when the precipitation

lack was protracted: in April there was 47% of the mean annual precipitation, in May – 17% and in June – 43%.

Results and discussion. The yields from winter triticale varieties and promising accessions in the competitive variety trial nursery averaged 6.93 and 7.78 t/ha when they were grown by conventional and intensive technologies, respectively (Tables 1, 2). The minimum yields were received with both technologies in 2013 (5.09 t/ha and 6.15 t/ha, respectively); the maximum yields – in 2017 (9.39 t/ha and 10.88 t/ha, respectively). The variational analysis of the average annual yield values showed that the modification (environmental) variability of this indicator was moderate (conventional technology) or considerable (intensive technology), indicating significant effects of the weather on the fulfillment of the biological potential of the winter triticale performance.

During the observation period, the grain number from the main spike in winter triticale averaged 48.4 (conventional technology) or 50.3 (intensive technology), with low environmental variability (8.02–9.19%). This level of the grain number was considered as high as per the Triticale classifier scale [8].

Table 1.

Winter triticale yield, performance and grain quality (competitive variety trial, conventional technology of cultivation)

Year	Yield, cwt/ha	Main spike		Test weight, g/L	1000-grain weight, g	Crude protein, * %	Gluten, %	Crude starch,* %
		grain number	grain weight, g					
2011	59.7	49.6	2.21	718	44.1	14.0	–	68.0
2012	68.2	42.4	1.83	709	43.5	9.9	–	71.9
2013	50.9	46.2	1.95	680	42.4	9.9	12.4	72.2
2014	77.9	44.1	2.08	730	47.1	10.5	14.2	71.5
2015	63.1	46.4	2.17	714	46.8	9.4	16.7	71.2
2016	71.6	46.1	2.02	670	43.9	9.6	18.2	68.8
2017	93.9	52.2	2.65	716	50.6	8.5	6.2	77.1
2018	62.7	49.5	2.49	706	50.6	11.2	14.7	72.5
2019	63.1	57.9	3.09	695	53.5	12.7	21.9	73.8
2020	82.2	49.3	2.34	711	47.6	13.7	18.9	71.7
Mean	69.3±3.9	48.4±1.4	2.28±0.12	705±6	47.0±1.2	10.9±0.6	15.4±1.7	71.9±0.8
Range	50.9–93.9	42.4–57.9	1.83–3.09	670–730	42.4–53.5	8.5–14.0	6.2–21.9	68.0–77.1
Coefficient of variation, %	18.01	9.16	16.50	2.59	7.77	17.40	31.01	3.49

Note: * adjusted for absolutely dry matter.

The maximum number of grains from the main spike (59.2) was recorded with intensive technology in 2019 (Table 2).

Differentiation of the average annual values of another constituent of the spike performance – grain weight - was more pronounced, as evidenced by the coefficients of variation of the trait (16.50–17.79%). Obviously, there should be a close positive correlation between these biometric parameters of the spike. Correlation analysis showed that in winter triticale accession grown by conventional technology the degree of contingency between the amount and weight of grain from the main spike was 92.0%. The use of additional elements of intensification somewhat weakened this relationship, reducing it to 81.4%.

It should also be noted that in 2019 the maximum performance of the main spike in winter triticale was combined with the minimum number of productive stems. Assessment of the effect of this trait on the spike parameters showed negative, medium and insignificant

coefficients of correlation. Thus, the share of changes in the indicators of the grain amount and weight from the main spike depending on the number of productive stems was about 30% for the both cultivation technologies.

Table 2.

Winter triticale performance and grain quality (competitive variety trial, intensive technology of cultivation)

Year	Yield, cwt/ha	Main spike		Test weight, g/L	1000-grain weight, g	Crude protein,* %	Gluten, %	Crude starch,* %
		grain number	grain weight, g					
2011	64.8	50.4	2.28	727	45.1	14.3	–	67.4
2012	79.8	47.7	2.02	705	42.3	10.8	–	70.3
2013	61.5	49.6	1.94	664	39.7	10.2	14.0	72.0
2014	81.3	45.4	2.01	742	43.5	11.0	16.3	71.4
2015	69.1	46.5	2.12	720	45.8	11.4	18.9	69.0
2016	72.8	47.6	2.01	655	42.3	12.2	25.6	65.3
2017	108.8	53.8	2.87	733	53.2	9.0	5.7	76.0
2018	68.9	51.5	2.72	712	53.1	11.8	19.1	71.2
2019	64.5	59.2	3.11	700	52.8	13.2	24.5	73.6
2020	106.9	51.0	2.59	709	50.9	14.0	20.0	71.9
Mean	77.8±5.4	50.3±1.3	2.37±0.13	707±9	46.9±1.6	11.8±0.5	18.0±2.2	70.8±1.0
Range	61.5–108.8	45.4–59.2	1.94–3.11	655–742	39.7–53.2	9.0–14.3	5.7–25.6	65.3–76.0
Coefficient of variation, %	21.90	8.02	17.79	3.96	11.00	14.25	34.87	4.30

Note: * adjusted for absolutely dry matter.

Features of the triticale grain structure affect technological indicators of the crop. The test weight in triticale is lower in comparison with wheat, which is due to longer and less spherical caryopses [9]. In addition, the triticale caryopsis has a wrinkled pericarp, increasing the outer surface area and negatively affecting the grain density and test weight. All the test weight values presented in Table 1 and Table 2 belonged to the middle category as per the classifier scale, since they were within the range of 651–751 g/L [8]. The test weight is the most environmentally stable quantitative trait of winter triticale.

The triticale grain size determines fairly high values of the 1000-grains weight exceeding corresponding values for rye and wheat grains. Recently, the indicator has stabilized at the optimal level for winter triticale (44–48 g), which, to a certain extent, allows combining the caryopsis compactness and plumpness. On average, over the observation period, the 1000-grain weight in the winter triticale accessions was 47.0 and 46.9 g upon conventional and intensive cultivation technologies, respectively. Additional methods of intensification did not significantly affect on this indicator, but increased the modification variability of the trait (Table 2).

Analysis of the correlations between the technological indicators, test weight and 1000-grain weight, showed positive insignificant correlation coefficients for conventional and intensive technologies of cultivation: $r = 0.26$ and 0.42 , respectively.

The storage substance contents in winter triticale grain of significantly differed, depending on the intensification of cultivation and the impact of the environment. The use of additional nitrogen and trace elements significantly increased the crude protein and gluten contents and, accordingly, decreased the crude starch content. The maximum protein content in winter triticale grain (14.3%) was recorded in 2011; it is the medium level as per the classifier scale. As the breeding practice has shown, achievement of a high amount of crude protein

($\geq 15.1\%$) in winter triticale grain grown in the soil-climatic zone of Belarus is a difficult challenge, especially if the performance potential of the genotype is preserved [10]. Its solution, along with methods of distant hybridization and molecular genetics, may be facilitated by global warming.

Typically, the gluten content in winter triticale is low, which is confirmed by data of the last eight-year observations. There was a strong significant ($p = 0.05$) correlation between the protein and gluten contents in winter triticale grain: correlation coefficients $r = 0.70$ (conventional technology) and 0.94 (intensive technology). Wide modification variability is a distinctive feature of the "gluten content" trait. The "starch content" trait, on the contrary, along with the test weight, is amongst the most stable quantitative traits in winter triticale. The starch content in grain varied slightly both over the study years and between the cultivation technologies.

The studied quantitative traits of the winter triticale accessions from the competitive variety trial nursery were characterized by different levels of genotypic (varietal) variability. Such indicators as the gluten content, yield and grain weight per ear per spike were the most variable, while the test weight and crude starch content – the least variable (Table 3). The genotypic variability of the other traits of winter triticale was moderate. It should be noted that the use of additional methods of intensification changed the absolute values of the indicators, but did not have a key effect on the level of their varietal variability.

Table 3.

Genotypic variability of quantitative traits in the winter triticale accessions: 1-conventional technology, 2-intensive technology (2011–2020, n = 285)

Trait	Range		Coefficient of variation, %	
Yield, t/ha	37.0–103.6	42.8–127.7	20.02	22.89
Grain number	29.6–68.6	32.9–74.9	13.06	13.46
Grain weight, g	1.35–3.81	1.29–3.78	19.97	20.71
Test weight, g/L	635–765	615–770	3.70	4.44
1000-grain weight, g	34.0–65.2	30.6–62.8	12.97	14.77
Crude protein, % (adjusted for absolutely dry matter)	7.5–15.3	7.7–16.1	17.04	15.37
Gluten*, %	2.6–29.5	2.2–32.7	33.35	38.38
Crude starch, % (adjusted for absolutely dry matter)	64.1–79.8	60.3–79.3	3.72	4.82

Note: * n= 235 accessions.

Conclusions. The study of the quantitative traits of winter triticale varieties and promising accessions grown in Belarus using conventional and intensive cultivation technologies allowed for assessments of their values and variability ranges. The maximum stability (environmental and genotypic) was intrinsic to such indicators of winter triticale as the test weight and crude starch content, while the minimum – to the gluten content and yield.

The use of additional methods of intensification changed the absolute values of the quantitative traits, but did not have a key effect on the level of their variability.

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МІНЛИВІСТЬ КІЛЬКІСНИХ ОЗНАК ОЗИМОГО ТРИТІКАЛЕ В УМОВАХ ЦЕНТРАЛЬНОГО РЕГІОНУ БІЛОРУСІ

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Мета. Оцінити мінливість кількісних ознак озимого тритікале, яке вирощується за звичайною та інтенсивною технологією в умовах Білорусі.

Матеріали і методи. Об'єктом дослідження були 30 сортів і перспективних зразків озимого гексаплоїдного тритікале (*X Triticosecale* Wittm. & A. Camus, $2n=42$) вітчизняної та закордонної селекції (Польща, Україна, Росія) з розсадника конкурсного сортовипробування. Зразки щорічно тестували на дослідних полях науково-

практичного центру Національної академії наук Білорусі по землеробству за звичайною та інтенсивною технологією вирощування. При інтенсивному рівні вирощування застосовували додаткову дозу азотних добрив, мікроелементи (Cu, Mn), регулятори росту та фунгіциди. Площа ділянки – 10 м², повторення – трьохкратне, розміщення ділянок рандомізоване, норма висіву 4,5 млн схожого насіння на гектар, період спостереження – 2011–2020 рр.

Визначено врожайність, кількість та масу зерен основного колоса, натуру і масу 1000 зерен. Вміст в зерні сирого протеїну, клейковини та крохмалю визначали методом ближньої інфрачервоної спектроскопії. Статистичну обробку даних проводили за Доспеховим Б.А.

Обговорення результатів. У статті представлено результати багаторічного вивчення кількісних ознак сортів і зразків озимого тритикале, вирощених в ґрунтово-кліматичних умовах центрального регіону Білорусі за звичайною та інтенсивною технологією. Показано ступінь впливу рівня інтенсифікації на врожайність, елементи продуктивності та якість зерна тритикале.

Висновки. Максимальною стабільністю характеризувалися показники озимого тритикале «натура зерна» та «вміст сирого крохмалю»; мінімальною – «вміст клейковини» та «врожайність». Застосування додаткових прийомів інтенсифікації змінювало абсолютні значення кількісних ознак, але не мало суттєвого впливу на рівень їх мінливості.

Ключові слова: тритикале озиме, технологія вирощування, врожайність, кількісна ознака, мінливість

ИЗМЕНЧИВОСТЬ КОЛИЧЕСТВЕННЫХ ПРИЗНАКОВ ОЗИМОГО ТРИТИКАЛЕ В УСЛОВИЯХ ЦЕНТРАЛЬНОГО РЕГИОНА БЕЛАРУСИ

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Цель. Оценить изменчивость количественных признаков озимого тритикале, выращиваемого по обычной и интенсивной технологиям возделывания в условиях Беларуси.

Материалы и методы. Объектом исследований были 30 сортов и перспективных образцов озимого гексаплоидного тритикале (*X Triticosecale* Wittm. & A. Camus, $2n=42$) отечественной и зарубежной селекции (Польша, Украина, Россия) из питомника конкурсного сортоиспытания. Образцы ежегодно тестировали на опытных полях научно-практического центра Национальной академии наук Беларуси по земледелию по обычной и интенсивной технологиям возделывания. При интенсивном уровне возделывания применяли дополнительную дозу азотных удобрений, микроэлементы (Cu, Mn), регуляторы роста и фунгициды. Площадь делянки – 10 м², повторение – трехкратное рандомизированное, норма высева 4,5 млн всхожих семян на гектар, период наблюдений – 2011–2020 гг.

Определили урожайность, количество и массу зерен главного колоса, натуру и массу 1000 зерен. Содержание в зерне сырого протеина, клейковины и крахмала определили методом ближней инфракрасной спектроскопии. Статистическую обработку данных проводили по Доспехову Б.А.

Обсуждение результатов.

В статье представлены результаты многолетнего изучения количественных признаков сортов и образцов озимого тритикале, выращиваемых в почвенно-климатических условиях центрального региона Беларуси по обычной и интенсивной технологиям возделывания. Показана степень влияния уровня интенсификации на урожайность, элементы продуктивности и качество зерна тритикале.

Выводы. Максимальной стабильностью характеризовались показатели озимого тритикале «натура зерна» и «содержание сырого крахмала»; минимальной – «содержание клейковины» и «урожайность». Применение дополнительных приемов интенсификации изменяло абсолютные значения количественных признаков, но не оказывало определяющего влияния на уровень их изменчивости.

Ключевые слова: тритикале озимое, технология возделывания, урожайность, количественные признаки, изменчивость

VARIABILITY OF QUANTITATIVE TRAITS IN WINTER TRITICALE IN THE CENTRAL REGION OF BELARUS

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Introduction: The article presents the results of a long-term study of quantitative traits in winter triticale varieties and accessions grown in the soil/climatic conditions of the central region of Belarus using conventional and intensive cultivation technologies. The effects of the intensification level on the yield, performance constituents and triticale grain quality are described.

Purpose: to assess the variability of quantitative traits in winter triticale grown by conventional and intensive cultivation technologies in Belarus.

Material and methods: Winter hexaploid triticale varieties and promising accessions grown by traditional and intensive technologies in a competitive variety trial nursery were studied. The plot area was 10 m²; the replication number was three; the design was randomized; the seeding rate was 4.5 million viable seeds per hectare; the observation period was in 2011-2020. Upon intensive cultivation, additional doses of nitrogen fertilizers, trace elements (Cu, Mn), growth regulators and fungicides were applied. The contents of crude protein, gluten and starch in grain were determined by near-infrared spectroscopy

Results and discussion: During the observation period, the average yield from the winter triticale accessions in the competitive variety trial nursery was on 69.3 dt/ha and 77.8 dt/ha upon the application of traditional and intensive cultivation technologies, respectively. The additional factors of intensification increased the yield by 8.5 dt/ha or by 12.3 %. The constituents of the main spike performance as well as contents of crude protein and gluten in winter triticale grain also grew. Strengthening of intensification of the cultivation technology didn't significantly affect the test weight, 1000-grain weight or crude protein content.

Conclusions. The use of additional methods of intensification was demonstrated to change the absolute values of the winter triticale indicators, to have no key impact on the level of their environmental of genotypic variability. The test weight and crude protein content were the most stable traits, while the gluten content and yield – the least stable ones, as their values were determined by both varietal specificity and environmental factors.

Key words: winter triticale, cultivation technology, yield, quantitative traits, variation.