

## VARIABILITY OF YIELD ATTRIBUTES FOR WINTER TRITICALE IN THE FOREST-STEPPE OF UKRAINE

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**Topicality.** The productivity of winter triticale varieties is determined by their genotype; however, the formation of its productivity as a whole and as individual components is particularly influenced by growing conditions. Therefore, it remains relevant to develop varieties that combine the highest yield potential with genetic resistance to limiting environmental factors. **Purpose.** To establish the variability of winter triticale yield attributes and to identify promising lines for involvement in breeding programs as source material. **Materials and Methods.** The studies were carried out at the V. M. Remeslo Myronivka Institute of Wheat NAAS of Ukraine. The Amur variety was used as the standard. Twenty breeding lines were studied. The area of the registration plot was 10 m<sup>2</sup>; the experiment was repeated four times. Laboratory-field and mathematical-statistical research methods were used. **Results.** Our research has found that the highest yield was 4.89 t/ha with variation from 3.98 (min) to 6.17 t/ha (max) in 2020/21, and the lowest yield was 4.33 t/ha with variation from 3.34 (min) to 5.09 t/ha (max) in 2021/22. During the research period, three breeding lines 23014, 23015, 23016 formed the medium spike; the rest of lines formed the long spike. It should be noted that the highest number of spikelets in spike (from 20.83 pcs (min) to 30.90 pcs (max)) was formed in 2020/21, which was characterized by excessive moisture conditions (HTC = 1.72), but it did not reveal a negative impact on formation of florets in spike, whereas under dry conditions (HTC = 0.80) in 2021/2022, the least number of spikelets in the spike (from 17.30 pcs (min) to 22.95 pcs (max)) was formed. The highest grain content per spike, regardless of the conditions of the growing season, was found in the lines 23019 (55.24 pcs), 23005 (53.21 pcs), 23017 (51.98 pcs), but they did not exceed the standard line (55.35 pcs). However, these lines are characterized by high productivity. **Conclusions.** Based on the results of the research, the breeding lines 22002, 22003, 22005, 22017, 23018, 22019 were selected according to their yield attributes; these lines can serve as a source material for development of high-yielding varieties in the Forest-Steppe of Ukraine. Determination of correlation coefficients revealed that the yield level is influenced by the spike productivity.

**Key words:** winter triticale, breeding lines, yield attributes, yielding capacity, correlation coefficients

**Introduction.** Winter triticale (*×Triticose-cale Wittmack*) is a unique hybrid that combines the characteristics of wheat and rye parental forms: high grain and green mass yield potential with enhanced adaptive properties such as drought resistance, low requirements to soils, pest and disease resistance, high protein content in grain and primary nutrients in green mass [1–4].

In recent years, breeders have created many new high-potential triticale varieties, the efficiency of which can be enhanced by improving their cultivation technologies for different soil and climatic conditions in Ukraine. The

development of high-quality wheat varieties based on triticale has resulted in genotypes with a unique protein complex that provides high nutritional value.

However, there is an opinion that a variety with an average stable yield has a higher ecological value than a variety with a potentially high unstable yield. Therefore, in order to obtain high and sustainable yields, hybrids with different types of response to environmental variability should be used [5].

At present, the genetic potential of varieties is realised only by 25–40 % due to reduced

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plant resistance to stress factors [6]. Increasing the productivity of this crop requires the development and introduction of varieties with a wide adaptive potential that can produce stable yields in unstable growing conditions.

The research was aimed at determining the variability of winter triticale productivity elements and identifying sources of source material for involvement in breeding programmes for the conditions of the Forest-Steppe of Ukraine.

**Materials and Methods.** The research was conducted at the V. M. Remeslo Myronivka Institute of Wheat of NAAS of Ukraine in 2020/21 and 2022/23. Winter triticale breeding lines were sown with a seeder SN-10Ts. A predecessor was soybean. The Amur variety was used as a standard. Twenty breeding lines were studied. Phenological observations were carried out according to the methodology for the State Variety Testing of Crops [7]. The registration

area of the plot was 10 m<sup>2</sup>; the experiment was repeated four times. Harvesting was carried out with a combine harvester Sampo-130.

As a qualitative characteristic of the favourable environmental conditions and the formation of productivity, the hydrothermal coefficient (HTC) was calculated according to the method of G. T. Selyaninov [8]. The following statistical parameters were calculated: arithmetic averages ( $\bar{x}$ ); minimum values ( $x_{\min}$ ); maximum values ( $x_{\max}$ ); coefficient of variation (V, %) according to the method of selection experiment (in crop production) [9].

**Results and Discussion.** The weather conditions varied significantly in terms of temperature and precipitation during the growing seasons of winter triticale in 2020/21–2022/2023, which gave an opportunity to evaluate and identify promising lines for the conditions of the Forest-Steppe of Ukraine (Fig. 1).

Sowing was carried out under conditions

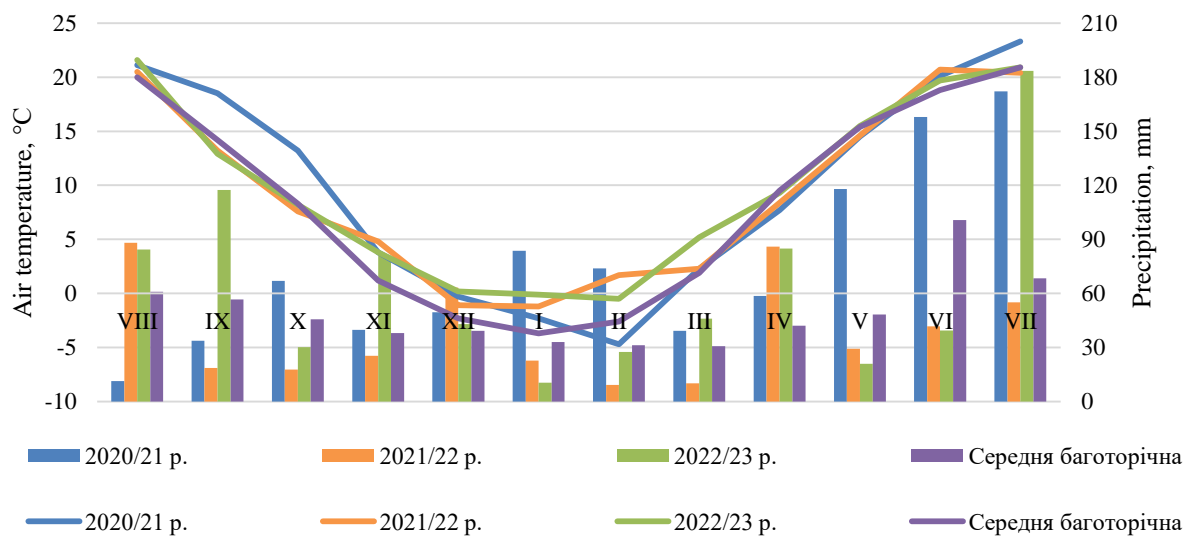


Fig. 1. Average monthly air temperature and precipitation during the growing seasons 2020/21–2022/23.

of insufficient moisture in autumn 2020. Thus, precipitation amounted to 33.8 mm in September, which is 22.8 mm below the long-term average. In the period from August to October, the air temperature exceeded the long-term average by 1.1–4.9 °C. During the same period, the moisture deficit ranged from 22.8 to 49.6 mm. The growth cessation of crop was observed on 11 November 2020. The lowest air temperature (-21.4 °C) was recorded on 17 January 2021. In general, the winter was quite mild, with the average temperature of -0.3 °C in December 2020,

which was 2.0°C higher than the long-term average; in January 2021, the average monthly temperature was -2.3 °C, which was also 1.4°C higher than the long-term average; in February 2021, the average temperature was -4.7°C, which was 2.1°C lower than the long-term average.

During the winter period of 2020/21, the maximum snow cover depth reached 30–45 cm, and the temperature at the tillering node depth ranged from 0 to -2 °C. Thus, in 2021, a temporary growth resumption of winter crops was observed on 14 March, and the final one on 26

March. In April and May 2021, the average air temperature was 0.9 and 1.8 °C below the long-term average, respectively, given the excessive moisture availability. During the period from the vegetative resumption to the end of July, precipitation amounted to 506.5 mm, which is 246.8 mm above the long-term average. The total precipitation for the year was 905.0 mm, which is 309.7 mm higher than the long-term average. In the 2020/21 growing season, the maximum precipitation (172.1 mm) was in July 2021, and the minimum (11.4 mm) was in August 2020.

Weather conditions were not favourable for sowing winter triticale for the 2022 harvest. September and October were characterised by a severe precipitation deficit of 35.0 and 23.5 mm compared to the long-term average, resulting in soil moisture loss. During the pre-sowing and sowing period (September – October), the average temperature was close to the long-term average. The precipitation deficit, which was 60–70 % of the precipitation norm for September–October, led to a gradual decrease in soil moisture reserves. However, low air temperatures, many cool days, abundant dew and fog did not result in drought.

The vegetation cessation of winter triticale was observed in mid-November. Overwintering of winter crops occurred under conditions of unstable snow cover or its absence, short-term sharp cold snaps and thaws. In November and December, the air temperature was above normal (by 2.9 and 0.6 °C). The spring growing season (April and May) was characterised by very dry conditions (HTC = 0.28, 0.65). In the spring-summer period, the maximum air temperature was 20.7 °C in June, with a moisture deficit of 43.6 mm. The total precipitation for the year was 467.6 mm, which is 114.2 mm less than the long-term average (581.8 mm). The hydrothermal coefficient for the growing season 2021/22 was 0.80, which corresponds to dry conditions.

In September, precipitation totalled 117.5 mm, which is 60.6 mm above the long-term average. In the period from September to October, the air temperature was 1.6–0.5 °C below the long-term average. In the same period (October), the moisture deficit was 10.1 mm. In general, the winter was quite mild, so in December 2022, the air temperature was 0.2 °C, which was 1.8 °C higher than the long-term

average; in January 2023, the average monthly temperature was -0.1 °C, which was also 3.3 °C higher than the long-term average; in February 2023, the air temperature was -0.5 °C, which was 1.7 °C higher than the long-term average.

The vegetative resumption of winter crops generally depended on the hydrothermal conditions of the research year. In April and May 2023, the average air temperature was 0.5 and 0.2 °C lower than the long-term average. The annual precipitation totalled 768.9 mm, which is 180.0 mm more than the long-term average. For the growing season 2022/23, the maximum precipitation (183.5 mm) fell in July 2023, and the minimum (10.6 mm) in January. The hydrothermal coefficient for the 2022/23 growing season was 1.52, which corresponds to conditions with sufficient moisture availability.

Different weather conditions of the growing season allowed us to obtain reliable data on their adaptability for the realisation of the productivity potential of winter triticale and to objectively assess the effect of the climatic factor in the zone on the variability and nature of the manifestation of the quantitative traits of the crop.

It was found that the highest yield was 4.89 t/ha in 2020/21, which varied from 3.98 t/ha (min) to 6.17 t/ha (max), and the lowest yield was 4.33 t/ha in 2021/22, which varied from 3.34 t/ha (min) to 5.09 t/ha (max). In the years of research, the average yield was 4.59 t/ha.

The peculiarities of winter triticale yield formation were revealed by analysing the spike productivity elements, the main of which are: main spike length, number of spikelets in spike, number of grains in spike.

The main spike length varied under the influence of climatic conditions prevailing during spike formation. The most important environmental factors affecting the main spike length are temperature, light intensity and day length [10]. During the period 2020/21–2022/23, three lines (23014, 23015, and 23016) formed a medium spike length, and the rest lines formed a long spike (Table 2). The variability of the traits was estimated by the coefficient of variation, i.e. the degree of phenotypic manifestation in plants depending on environmental conditions was determined. According to the data obtained, the coefficient of variation ranged from low to medium ( $V = 0.58\text{--}13.22\%$ ) over the years of research.

**Table 1. Yield parameters of the best winter triticale lines (for 2020/21–2022/23)**

Line	Yields, t/ha				Statistical parameters			
	2020/21	2021/22	2022/23	$\bar{x}$	min	max	$\sigma_d^2$	V, %
Amur variety (standard)	4.23	4.69	4.09	4.34	4.09	4.69	0.31	7.24
23002	5.77	4.71	5.51	5.33	4.71	5.77	0.55	10.36
23011	5.27	4.72	4.81	4.93	4.72	5.27	0.30	5.98
23008	5.61	4.7	4.13	4.81	4.13	5.61	0.75	15.51
LSD <sub>05</sub>	0.41							

*Notes.* Values for the experiment:  $\bar{x}$  – mean value, min – minimum values, max – maximum values,  $\sigma_d^2$  – standard deviation, V, % – coefficient of variation.

**Table 2. Parameters of main spike length in the winter triticale lines (for 2020/21–2022/23)**

Line	Main spike length, cm			Statistical parameters				
	2020/21	2021/22	2022/23	$\bar{x}$	min	max	$\sigma_d^2$	V, %
Amur variety (standard)	9.80	12.65	10.80	11.08	9.80	12.65	1.45	13.05
23002	11.57	11.80	11.00	11.46	11.00	11.80	0.41	3.60
23003	12.60	11.90	12.00	12.17	11.90	12.60	0.38	3.11
23004	9.60	11.30	11.00	10.63	9.60	11.30	0.91	8.53
23005	12.17	9.50	10.30	10.66	9.50	12.17	1.37	12.84
23006	11.50	9.40	10.50	10.47	9.40	11.50	1.05	10.04
23007	10.00	10.70	10.00	10.23	10.00	10.70	0.40	3.95
23008	10.30	10.40	10.20	10.30	10.20	10.40	0.10	0.97
23009	9.50	10.90	10.10	10.17	9.50	10.90	0.70	6.91
23010	9.25	11.70	10.70	10.55	9.25	11.70	1.23	11.68
23011	10.00	10.10	10.00	10.03	10.00	10.10	0.06	0.58
23012	10.90	9.60	10.10	10.20	9.60	10.90	0.66	6.43
23013	12.20	10.70	11.10	11.33	10.70	12.20	0.78	6.85
23014	9.14	11.10	9.50	9.91	9.14	11.10	1.04	10.51
23015	9.40	9.00	9.00	9.13	9.00	9.40	0.23	2.53
23016	9.63	9.50	9.40	9.51	9.40	9.63	0.11	1.19
23017	11.25	10.70	10.90	10.95	10.70	11.25	0.28	2.54
23018	11.40	10.10	10.50	10.67	10.10	11.40	0.67	6.24
23019	9.86	12.80	11.00	11.22	9.86	12.80	1.48	13.22
min	9.14	9.00	9.00	9.13	9.00	9.40	0.06	0.58
max	12.60	12.80	12.00	12.18	11.90	12.80	1.48	13.22

*Notes.* Values for the experiment:  $\bar{x}$  – mean value, min – minimum values, max – maximum values,  $\sigma_d^2$  – standard deviation, V, % – coefficient of variation.

According to the experimental data, the lines formed the largest number of spikelets per spikelet in the growing season 2020/21 (min – 20.83 pcs, max – 30.90 pcs), which was characterised by excessive moisture conditions (HTC = 1.72), and in arid conditions of 2021/22 (HTC = 0.80), the smallest number of spikelets per spike was formed (min – 17.30 pcs, max – 22.95 pcs.) The coefficient of variation ranged from insignificant to high (V = 0.24–22.35 %) over the years of research (Table 3).

One of the key elements of the yield attributes is the number of grains per spike. The spike grain content depends on genotypic characteristics, namely spike length, number of spikelets, floret fertility, as well as on environmental conditions during flowering, pollination and fertilisation. The trait ‘number of grains per main spike’ is characterised by low variability and is an important element of spike productivity [11]. On average for three years, regardless of the weather conditions, the highest grain content

**Table 3. Parameters of number of spikelets per spike in the winter triticale lines, (for 2020/21–2022/23)**

Line	Number of spikelets per spike, pcs.			Statistical parameters				
	2020/21	2021/22	2022/23	$\bar{x}$	min	max	$\sigma_d^2$	V, %
Amur variety (standard)	26.25	22.95	24.30	24.50	22.95	26.25	1.66	6.77
23002	26.14	19.00	22.00	22.38	19.00	26.14	3.59	16.03
23003	25.40	19.90	24.20	23.17	19.90	25.40	2.89	12.48
23004	24.50	19.10	20.00	21.20	19.10	24.50	2.89	13.65
23005	28.67	19.50	25.30	24.49	19.50	28.67	4.64	18.93
23006	26.10	17.80	21.00	21.63	17.80	26.10	4.19	19.35
23007	21.57	21.70	21.70	21.66	21.57	21.70	0.07	0.34
23008	24.90	20.10	22.30	22.43	20.10	24.90	2.40	10.71
23009	20.83	20.90	20.80	20.84	20.80	20.90	0.05	0.24
23010	23.50	21.40	22.00	22.30	21.40	23.50	1.08	4.85
23011	26.67	19.30	21.00	22.32	19.30	26.67	3.86	17.28
23012	27.80	20.10	24.30	24.07	20.10	27.80	3.86	16.02
23013	30.90	20.20	26.70	25.93	20.20	30.90	5.39	20.79
23014	21.86	19.80	20.10	20.59	19.80	21.86	1.11	5.40
23015	22.10	18.10	21.00	20.40	18.10	22.10	2.07	10.13
23016	25.25	17.30	19.00	20.52	17.30	25.25	4.19	20.40
23017	28.50	20.60	26.70	25.27	20.60	28.50	4.14	16.39
23018	29.00	18.60	27.30	24.97	18.60	29.00	5.58	22.35
23019	26.71	21.70	24.00	24.14	21.70	26.71	2.51	10.40
min	20.83	17.30	19.00	20.40	17.30	20.90	0.05	0.24
max	30.90	22.95	27.30	25.93	22.95	30.90	5.58	22.35

**Notes.** Values for the experiment:  $\bar{x}$  – mean value, min – minimum values, max – maximum values,  $\sigma_d^2$  – standard deviation, V, % – coefficient of variation.

was found in the high productive lines 23019 (55.24 pcs.), 23005 (53.21 pcs.), 23017 (51.98 pcs.), but they did not exceed the standard line (55.35 pcs.) (Table 4).

Over the years of research, the coefficient of variation ranged from low to high (V = 0.89–22.77 %). It was found that the influence of environmental conditions on winter triticale lines occurred in a certain period of their development and, as a result, all this affected the indicators of grain content of the spike.

The spike productivity elements are interconnected in many cases by undesirable correlations, so studying the correlations allows us to identify which components can increase triticle yield and thus increase the efficiency of breeding work [12, 13]. In this context, studying correlations between quantitative plant traits and determining the proportion of variability that

depends on the effect of one trait on another is relevant [14]. The correlation between the winter triticale yield and the spike productivity elements was analysed (Table 5). According to the correlation analysis, there is a moderate relationship between the yield and the length of the main spike ( $r = 0.38 \pm 0.06$ ), 1000 grain weight ( $r = 0.46 \pm 0.10$ ); main spike length and the number of spikelets in the spike ( $r = 0.33 \pm 0.06$ ). A significant correlation was observed between yield and number of grains per spike ( $r = 0.52 \pm 0.10$ ); spike length and number of grains per spike ( $r = 0.64 \pm 0.10$ ); number of grains per spike and number of spikelets per spike ( $r = 0.62 \pm 0.09$ ); number of spikelets per spike and 1000 grain weight ( $r = 0.55 \pm 0.10$ ). A weak relationship was established between the spike length and 1000 grain weight ( $r = 0.25 \pm 0.05$ ); number of grains per spike and 1000 grain weight ( $r = 0.27 \pm 0.05$ ).

**Table 4. Parameters of number of grains per spike in the winter triticale lines, (for 2020/21–2022/23)**

Line	Number of grains per spike, pcs.			Statistical parameters				
	2020/21	2021/22	2022/23	$\bar{x}$	min	max	$\sigma_d^2$	V, %
Amur variety (standard)	49.45	61.60	55.00	55.35	49.45	61.60	6.08	10.99
23002	57.57	37.50	44.00	46.36	37.50	57.57	10.24	22.09
23003	44.30	43.50	43.70	43.83	43.50	44.30	0.42	0.95
23004	35.40	50.40	42.10	42.63	35.40	50.40	7.51	17.63
23005	64.33	40.30	55.00	53.21	40.30	64.33	12.12	22.77
23006	46.40	47.20	47.00	46.87	46.40	47.20	0.42	0.89
23007	34.43	47.70	40.00	40.71	34.43	47.70	6.66	16.37
23008	48.00	45.30	46.00	46.43	45.30	48.00	1.40	3.02
23009	32.00	50.90	45.00	42.63	32.00	50.90	9.67	22.68
23010	31.75	48.00	42.00	40.58	31.75	48.00	8.22	20.25
23011	47.89	41.20	46.00	45.03	41.20	47.89	3.45	7.66
23012	51.00	48.00	47.00	48.67	47.00	51.00	2.08	4.28
23013	45.80	49.20	44.00	46.33	44.00	49.20	2.64	5.70
23014	42.14	47.30	43.00	44.15	42.14	47.30	2.76	6.26
23015	40.30	46.00	42.00	42.77	40.30	46.00	2.93	6.84
23016	40.13	44.00	43.00	42.38	40.13	44.00	2.01	4.75
23017	49.75	54.20	52.00	51.98	49.75	54.20	2.23	4.28
23018	53.80	40.80	50.00	48.20	40.80	53.80	6.68	13.87
23019	55.43	56.30	54.00	55.24	54.00	56.30	1.16	2.10
min	31.75	37.50	40.00	40.58	31.75	44.00	0.42	0.89
max	64.33	61.60	55.00	55.35	54.00	64.33	12.12	22.77

*Notes.* Values for the experiment:  $\bar{x}$  – mean value, min – minimum values, max – maximum values,  $\sigma_d^2$  – standard deviation, V, % – coefficient of variation.

**Table 5. Correlation coefficients between yield and spike productivity elements of the winter triticale lines (for 2020/21–2022/23)**

Trait	Main spike length, cm	Number of grains per spike, pcs.	Number of spikelet per spike, pcs.	1,000 grain weight, g
Yield, t/ha	0.38±0.06	0.52±0.10	0.51±0.09	0.46±0.10
Main spike length, cm	x	0.64±0.10	0.33±0.06	0.25±0.05
Number of grains per spike, pcs.	-	x	0.62±0.09	0.27±0.05
Number of spikelet per spike, pcs.	-	-	x	0.55±0.10
1,000 grain weight, g	-	-	-	x

Therefore, improving the efficiency of the breeding process requires an in-depth study of the relationship between yield attributes and quality indicators, the impact of limiting factors and the level of manifestations of valuable traits and properties.

**Conclusions.** The hydrothermal conditions of the research period 2020/21–2022/23 differed from the average long-term indicators in terms of temperature, precipitation and their

distribution in certain periods of plant growth and development. The parameters of variability in the spike productivity elements were established, which allowed us to identify promising lines of winter triticale 22002, 23003, 23019, 23005, 23017, 23018 for their involvement in breeding programmes as source material. Different degrees of correlation coefficients between spike productivity elements and yield were determined.

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**Федоренко М. В., Федоренко І. В., Близнюк Р. М., Іванцова Л. В. Мінливість показників елементів структури урожаю тритикале озимого в умовах Лісостепу України.**

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**Актуальність.** Продуктивність сортів тритикале озимого визначається генотипом, проте формування їх рівня у цілому і окремих структурних елементів знаходиться, зокрема, і під впливом умов вирощування, тому залишається актуальним створення сортів, що поєднують найвищий потенціал врожайності з генетичною резистентністю до лімітуючих факторів навколишнього природного середовища. **Мета.** Встановити рівень мінливості елементів структури продуктивності тритикале озимого та виділити джерела для залучення в селекційні програми в якості вихідного матеріалу. **Матеріали та методи.** Дослідження проводили в Миронівському інституті пшениці імені В. М. Ремесла НААН України. За стандарт використовували сорт Амур. Досліджували 20 селекційних ліній. Облікова площа ділянки становила 10 м<sup>2</sup>, повторність досліду чотириразова. Використовували лабораторно-польовий та математично-статистичні методи досліджень. **Результати.** Виявлено, що врожайність, за роки досліджень була найвищою у 2020/2021 р. – 4,89 з варіюванням від 3,98 (min) до 6,17 т/га (max), а найнижчою у 2021/2022 р. – 4,33 з варіюванням від 3,34 (min) до 5,09 т/га (max). За період до-

сліджень три лінії сформували колос середньої довжини – 23014, 23015, 23016, решта – довгий. Слід зазначити, що більшу кількість колосків у колосі, (min – 20,83 шт., max – 30,90 шт.), лінії сформували у 2020/2021 р., який характеризувався надмірними умовами зволоження (ГТК = 1,72), що не вплинуло на формування кількості квіток у колосі, а при посушливих умовах зволоження (ГТК = 0,80) у 2021/2022 р. сформувалася найменша кількість колосків у колосі (min – 17,30 шт., max – 22,95 шт.). Найбільшу озерненість колоса незалежно від умов року вирощування виявлено у ліній 23019 (55,24 шт.), 23005 (53,21 шт.), 23017 (51,98 шт.), але вони не перевищували стандарт (55,35 шт.), однак їх можна характеризувати як лінії з високим рівнем продуктивності. **Висновки.** За результатами досліджень виділено селекційні лінії – 22002, 22003, 22019, 22005, 22017, 23018 за показниками елементів структури продуктивності, що можуть слугувати вихідним матеріалом при створенні високопродуктивних сортів в умовах Лісостепу України. Визначення коефіцієнтів кореляції за елементами продуктивності дало змогу виявити, що на рівень врожайності впливають у різній мірі елементи структури колоса.

**Ключові слова:** *тритикале озиме, селекційні лінії, елементи структури урожаю, урожайність, коефіцієнт кореляції.*