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Productivity and grain quality of winter triticale varieties (*Triticosecale* Wittmack el. Camus) under different soil and climatic growing conditions

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Purpose. To evaluate the productivity and grain quality of winter triticale varieties grown under different soil and climatic conditions. **Methods.** The research process involved laboratory, computational and statistical methods, and analysis and synthesis to draw conclusions. **Results.** HTC (IV–X) was found to vary significantly monthly, annually and in general between the research sites. It was found that the yield of winter triticale varieties in the Forest-Steppe and Polissia zones was 5.3 t/ha. The maximum yield in the Forest-Steppe zone was achieved by the variety 'MIP Feniks' (5.9 t/ha), in the Polissia zone by the variety 'Pamiati Patseky' (5.8 t/ha). It was found that the protein content of winter triticale varieties for the 2019–2020 research years in the Forest-Steppe zone was on average 12.6% and ranged from 12.2% ('Liubomyr') to 13.3% ('MIP Yatahan'), which according to the classifier corresponded to grain of medium quality and can be used in the confectionery industry. The coefficient of variation (V,%) for this characteristic was 3.5%. In the Polissia zone, the protein content of the varieties averaged 13.6% over the years of research and ranged from 12.9% – medium content ('MIP Feniks') to 14.3% – high content ('MIP Yatahan'). The intrazone variation was low and amounted to 4.0%. Correlation and regression analysis showed that an increase in the active temperature during the vegetation period up to 3203 °C allows an increase in the productivity indicators and in the weight of 1000 grains from 5.6 to 6.1 t/ha and from 46.8 to 53.5 g, respectively; an increase in precipitation during the vegetation period up to 515.1 mm leads to a decrease in the weight of 1000 grains from 45.2 to 38.1 g; with an increase in the amount of active temperatures and precipitation during the vegetation period from 3167.65 to 3202.9 °C and from 413.85 to 515.1 mm, respectively, it is possible to increase the protein content in grain from 12.4 to 13.8%; with an increase in the yield and weight of 1000 grains from 5.8 to 6.1 t/ha and from 51.8 to 53.8 g, the protein content of the grain can be reduced from 13.1 to 12.0%. **Conclusions.** Different responses of varieties to zonal growing conditions were observed. A positive influence of the rainfall factor during the growing season on the yield of winter triticale in Forest-Steppe and Polissia (r = 0.66 and 0.34 units) and on the increase of the protein content of grain grown in the Polissia zone (r = 0.56) was revealed.

Keywords: *cereals; nutritional value; hydrothermal coefficient; cultivation capacity; protein content; correlation and regression analysis.*

Introduction

The ever-increasing world population and the demand for food for humans and animals mean that the main task of modern agricultural production is to provide high-quality plant raw materials and an effective diversification of cultivated plants [1].

The main direction of the creation of a new artificial genus of triticale (*Triticosecale* Wittmack el. Camus) in the *Poaceae* family was the combination in a distant hybrid of high productivity and quality of wheat grain with signs of adaptability and resistance to adverse abiotic and biotic environmental factors inherent in rye [2].

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The world area under triticale cultivation is constantly increasing and currently amounts to 3.8 million hectares [3]. Thanks to active breeding, new high quality varieties of triticale for food, technical and fodder purposes have been created. As of May 16, 2023, there are 73 varieties of triticale in the State Register of Plant Varieties suitable for distribution in Ukraine [4]. The main part of varieties, 75% (55 pcs.) of the winter type of development, 23% (17 pcs.) – spring, winter and spring type (alternate type) is represented by only one variety (2%). Interest in this multifunctional crop is due to a number of positive characteristics [5, 6].

New varieties are characterised by increased winter hardiness, drought resistance, resistance to the most dangerous diseases, high yield, biologically valuable protein content, which determines the fodder and nutritional value of this crop [7].

Triticale has a high adaptability to different climatic anomalies, which contributes to a stable grain yield [6, 8, 12]. Triticale is undemanding of soils and grows fairly well on all soil types. When sown on fertile soils, it surpasses rye in grain yield, and on poor soils or after poor predecessors, it surpasses wheat [12, 13]. Its nutritional properties make it a valuable animal feed and it is currently the most widely used feed for animals (mainly poultry, pigs and ruminants). Triticale grain is rich in starch and cellulose, so it can be used in the energy industry to produce biofuel [14, 15] and straw, as well as directly for heating [16]. In recent years, the cultivation of triticale for human consumption has become popular [17]. Thanks to its nutritional properties, triticale grain can also be used in the bakery industry, where cereal products are a valuable source of phenolic acids [18–20]. However, it should be added that the factors limiting such use of triticale are its high amylolytic activity and low gluten content, which negatively affect the bread baking process [21, 22].

Less precipitation, less soil moisture and lower groundwater levels are the result of drier conditions. Therefore, in the context of a changing climate, it is very important to have strategies for agricultural production that respond to these changes [1].

The growth and development of winter triticale from seedling to technical maturity takes 250–325 days, depending on the variety and growing conditions, including 40–60 days in autumn, with the sum of active temperatures during this period ranging from 1800–2300 °C. Seeds begin to germinate at a soil temperature of 1–3 °C [23]. Seedlings appear after 5–7 days. The optimum temperature for growth and development of winter triticale is 20–22 °C and the maximum temperature is up to 35 °C. The critical minus temperature for winter forms of triticale in the winter period is minus 18–20 °C in the bushing node zone. In the winter-spring period, triticale is less sensitive to low temperatures than winter wheat, due to the presence of rye genes in the genome of this crop [24].

Under the influence of weather conditions, the plant goes through two phases of hardening [5, 11]. A slightly positive average daily temperature of 6-0 °C (10–15 °C during the day and plus 1-minus 2 °C at night) is optimal for the first phase. Under such conditions, sugars (protective substances) accumulate in the nodes of the shoots and leaves during the day and their consumption slows down at night. On average, 20–25% of sugars (per unit of dry weight) accumulate in plants before they go dormant. Under such temperature conditions, which last 12–15 (20) days, the frost resistance of plants increases from minus 5 °C to minus 10–12 °C. When the duration of the first hardening phase increases to 30–40 days, the frost resistance of plants decreases [25].

The second stage of hardening occurs only after the first stage has been completed in frozen plants at a slightly negative average daily air temperature of minus 3–5 °C. Dehydration of the tissues and an increase in the concentration of cell sap during this period increase the winter hardiness of the plants.

Thanks to a well-developed root system, winter triticale outpaces wheat in growth even after germination, and a significant wax coating on the shoots contributes to increased drought resistance of the plants. However, in dry weather, during the period of intensive growth of the vegetative mass (the phase of tuberisation and grain spilling), triticale plants form small grains, the weight of which per 1000 grains does not exceed 35–40 g, instead of the usual weight of 50–55 g [11].

According to a number of scientists, several factors influence the quantity and quality of the cereal crop: variety, agro-technical measures, climatic and soil conditions, fertilisation and measures taken when agrophages appear [9, 17, 21].

The evaluation of climatic and agroclimatic indicators, or the zoning of the territory, gives an idea of the differences and quantitative parameters of heat and moisture resources of each region of Ukraine. The agroclimatic zoning of the territory of Ukraine, which is still in use today, was carried out in 1986 with the aim of rational use of climatic resources, optimal location of the main agricultural crops and increasing agricultural productivity. For this purpose, data of meteorological observations (temperature, precipitation) for the period 1956–1985 were used, as well as the criterion of humidification of territories, which allows a fairly objective assessment of the availability of moisture and heat – the Selyaninov's hydrothermal coefficient (HTC) [26].

The purpose of the research is to evaluate the indicators of productivity and grain quality of modern varieties of winter triticale grown under different soil and climatic conditions of Ukraine and to study their dependence.

Materials and methods

Six varieties of winter triticale – 'MIP Yatahan', 'MIP Feniks', 'Pamiati Patseky', 'Solodiuk', 'Liubomyr' and 'Myronosets' included in the State Register of Plant Varieties suitable for distribution in Ukraine in 2020–2021 were studied. Forest-Steppe and Polissia are recommended growing areas for them.

Field research was conducted in 2019–2020 in the research fields of branches of the Ukrainian Institute for Plant Variety Examination (UIPVE) in two soil and climate zones: Forest-Steppe (Sumy, Kharkiv, Khmelnytskyi and Chernivtsi regions); Polissia (Zhytomyr, Ivano-Frankivsk, Rivne, Chernihiv and Transcarpathian regions) in accordance with Methodology of qualification examination of plant varieties for suitability for distribution in Ukraine. General part and Methods of examination of plant varieties of the grain, cereal and legume group for suitability for distribution in Ukraine [27, 28]. The soils of the experimental plots were typical of the corresponding growing zone (Forest-Steppe and Polissia). The registered area of the plot was 25 m^2 and the placement of the plots was randomised, with four replications.

Laboratory studies were carried out in the laboratory of quality indicators of plant varieties of UIPVE in accordance with the Methodology for qualification examination of plant varieties for suitability for distribution in Ukraine. Methods of determining quality indicators of plant production [29].

Protein content in grain was determined by the express method on 500 g samples in ten replicates using an Infratec 1241 Infrared Grain Analyser (FOSS, Denmark).

Selyaninov's hydrothermal coefficient (HTC) was calculated using the formula

$$HTC = \frac{\sum R}{0{,}1 \times \sum t_{act} > 10}$$

where $\sum R$ is the amount of precipitation in mm during the period with temperatures above 10 °C; $0.1 \times \sum t_{act} > 10$ – the sum of active temperatures during the same period reduced by a factor of 10.

When HTC < 0.4 – very severe drought; HTC between 0.4 and 0.5 – severe drought; HTC from 0.6 to 0.7 – moderate drought; HTC from 0.8 to 0.9 – weak drought; HTC from 1.0 to 1.5 – sufficient humidity; HTC > 1.5 – excessively wet [26].

Wetting conditions were estimated by comparing the amount of precipitation for a given period with multi-year averages according to the formula:

$$V = \frac{100 \times \sum R_{i=01}}{\sum R^{01}_{i=01}}$$

where V is the deviation from the norm, %; $\sum R^{01}_{i=01}$ – multiannual average precipitation for a given period, mm; $\sum R_{i=01}$ – precipitation in a given year for the same period, mm; 100 – conversion into percentages; If V > 20%, the deviation from the norm is significant.

The statistical analysis of the research data was carried out using the methods of dispersion, correlation analysis and variational statistics of the field experiment using a personal computer.

Results and discussion

Weather conditions are one of the most important factors influencing the productivity of winter triticale, changing annually both in terms of improving and worsening vegetation conditions, and the level of yield is largely dependent on them.

The climate in the study areas is temperate continental, characterised by rather hot and dry summers and mild winters with frequent thaws. In recent years, climatic changes have been observed, as a result of which the pre-sowing period of winter crops is characterised by an exceedance of the long-term average air temperature indicators, a lack of or insufficient rainfall and an uneven distribution over the territory.

Information on temperature fluctuations, precipitation dynamics in the Forest-Steppe and Polissia zones in comparison with long-term data compiled from observations of agrometeorological stations in the cities of Sumy, Khmelnytskyi, Ivano-Frankivsk and Rivne are shown in Fig. 1, 2. According to the received data, the average air temperature in 2019 and 2020 on the territory of the Ukrainian Forest-Steppe and Polissia was higher than the norm (1961–1990) by 3.8 and 0.3 °C and amounted to plus 10.1–10.9 (Forest-Steppe) and 9.71–10.1 (Polissia) °C, respectively.

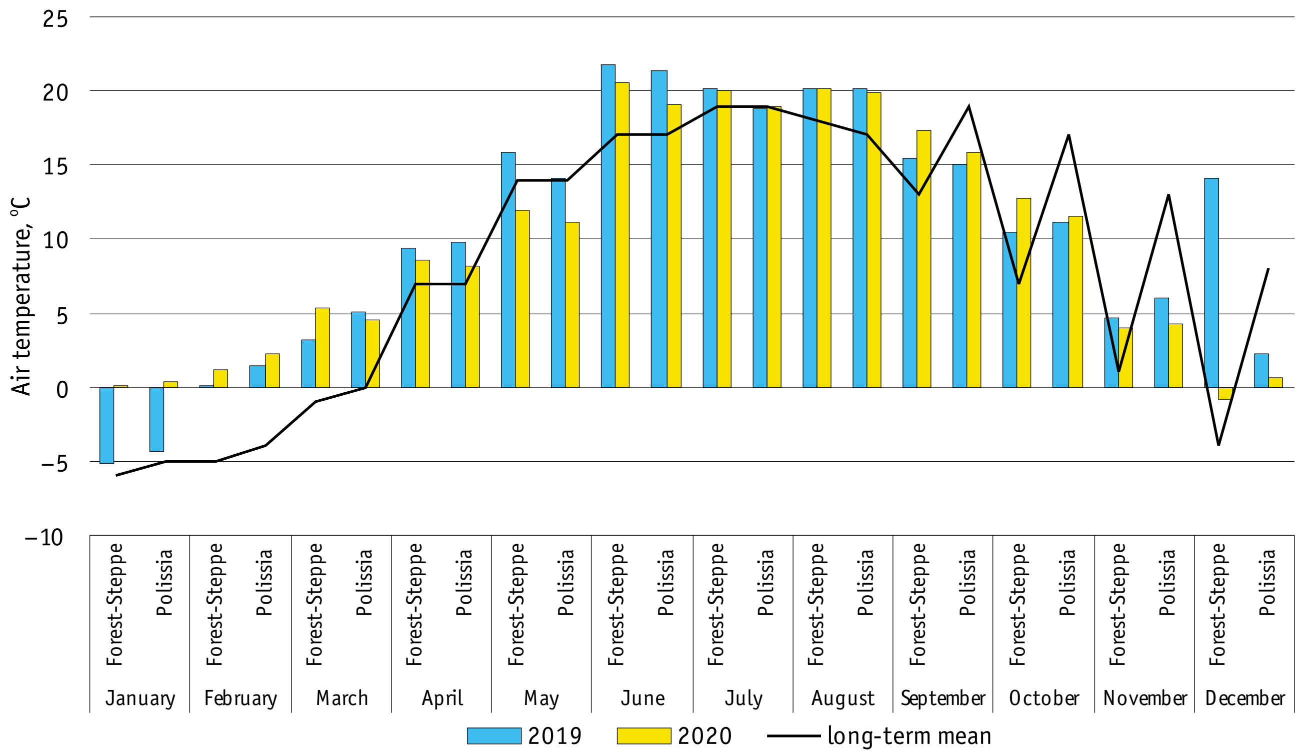

Fig. 1. The average monthly and multi-year air temperature for the 2019–2020 research years

The average annual precipitation for 2019 and 2020 is 519 (Forest-Steppe) and 690 (Polissia) mm (91 and 121% of the annual norm, respectively).

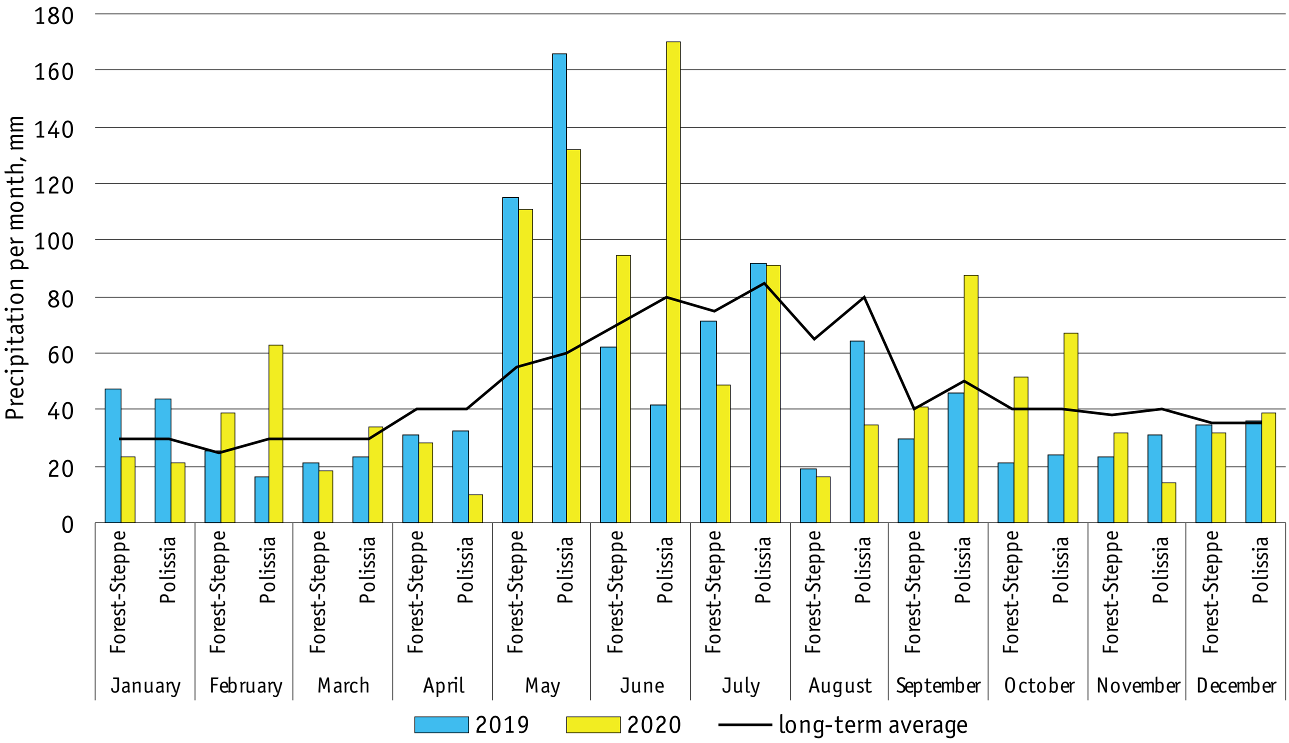

Fig. 2. Average monthly and multi-year precipitation for the 2019–2020 research years

In recent years, the meteorological and climatic conditions of the Ukrainian Forest-Steppe and Polissia zones have been quite favourable for the cultivation of winter cereals. This is true, first of all, of the winter and spring-summer periods, which are characterised by a moderate temperature regime and sufficient precipitation. However, in certain periods of the growing season, the uneven distribution of climatic factors sometimes creates unfavourable conditions for plant growth and development, which ultimately affects yield.

In general, during the 2019–2020 study period, the average annual air temperature ranged from 9.9 to 10.5 °C, an increase of 1.49 to 2.08 °C compared to the multi-year average data. The average precipitation for 2019 and 2020 was 559 and 649 mm respectively (98 and 114% of the annual norm). Despite the considerable variety of weather conditions, their deviation from the multi-year averages in certain periods of growth and development, the weather conditions of 2019–2020 were favourable for the growth and development of winter triticale.

An average warming of 1.5 °C increases the risk of heat waves (abnormally hot periods) and heavy precipitation. Rising temperatures will cause many rivers and lakes to dry up, accelerating the natural water cycle. In such a scenario, the uneven distribution of the annual precipitation rate will increase, i.e. the seasonal precipitation rate for the region may fall in a few days as a result of heavy rainfall [30].

The results of the calculations shown in Figure 3 allow us to conclude that, in general, the study years did not differ significantly from the norm in terms of precipitation. In general, the deviations from the norm were found to be insignificant in both zones, with precipitation being 10% below normal in 2019 and 9% above normal in 2020.

In 2019, March (82%), July (97%) and December (96%) were within the norm; February (67%), April (74%), June (62%), August (48%), September (78%), October (48%) and November (64%) were below the norm; only January (133%) and May (212%) were significantly above the norm.

In 2020, average precipitation was within the norm in March (92%), July (89%) and December (96%); it was below the norm in January (79%), April (35%), August (32%) and November (59%); it was significantly above the norm in February (168%), May (192%), June (181%), September (117%) and October (139%).

In Ukraine, hydrological conditions are a limiting factor for the productivity of agricultural crops. It is possible to estimate the hydrological factor using the indicator of the Selyaninov's HTC, which uses the assessment of moisture conditions in the period of average daily air temperatures above 10 °C, i.e. the period of active vegetation. HTC is a comprehensive indicator for the assessment of humidity conditions, taking into account both the inflow of water in the form of precipitation and the total amount spent on evaporation [31].

To characterise the meteorological factors, we used the HTC of the main periods of plant vegetation: sowing – the end of autumn vegetation and spring vegetation – wax ripening. According to the gradation of H. G. Selyaninov, the meteorological factors in 2019–2020 were generally characterised as slightly arid for the Forest-Steppe zone and moderately humid for the Polissia zone (Table 1).

It was found that HTC (IV–X) varies significantly monthly, annually and in general at the locations where the experiments were carried out. The best hydrothermal conditions for grain growth were observed in the Khmelnytskyi (HTC = 1.0–1.3 – adequate moisture) and Rivne (HTC = 1.2–1.4 – adequate moisture) branches. They were slightly worse in the Sumy (HTC = 0.5–0.8 – severe and mild drought) and Ivano-Frankivsk (HTC = 1.4–1.9 – too wet) branches.

Table 1

Selyaninov's HTC according to the average daily data for the research in 2019–2020

Branch	April		May		June		July		August		September		October		Average	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Forest-Steppe															0.8	1.0
Sumy	0.1	0.0	0.8	**2.6**	0.3	1.1	1.0	1.0	0.1	0.1	0.6	0.3	0.6	0.2	0.5	0.8
Khmelnytskyi	0.4	0.2	**2.8**	**2.1**	1.2	**2.5**	1.1	0.9	0.6	0.2	0.4	1.2	0.3	**1.9**	1.0	1.3
Polissia															1.3	1.6
Ivano-Frankivsk	0.8	0.4	**5.1**	**2.1**	0.9	**4.2**	1.5	**2.1**	0.3	0.4	1.1	**2.4**	0.4	1.8	1.4	**1.9**
Rivne	**1.6**	0.1	**2.1**	**3.2**	0.7	**2.1**	**1.9**	1.2	1.2	0.9	0.9	1.0	0.3	1.0	1.2	1.4

The values of HTC in the 2019 season fluctuated in wide gradations: from weak drought (HTC = 0.8) in the Sumy branch to excessive drought (HTC = 5.1) in the Ivano-Frankivsk branch.

As a result of the research it was determined that the average yield of winter triticale varieties in the Forest-Steppe and Polissia zone in 2019–2020 will be 5.3 t/ha.

The maximum yield in the Forest-Steppe zone was achieved by the variety 'MIP Feniks' – 5.9 t/ha, in the Polissia zone by the variety 'Pamiati Patseky' – 5.8 t/ha (Table 2).

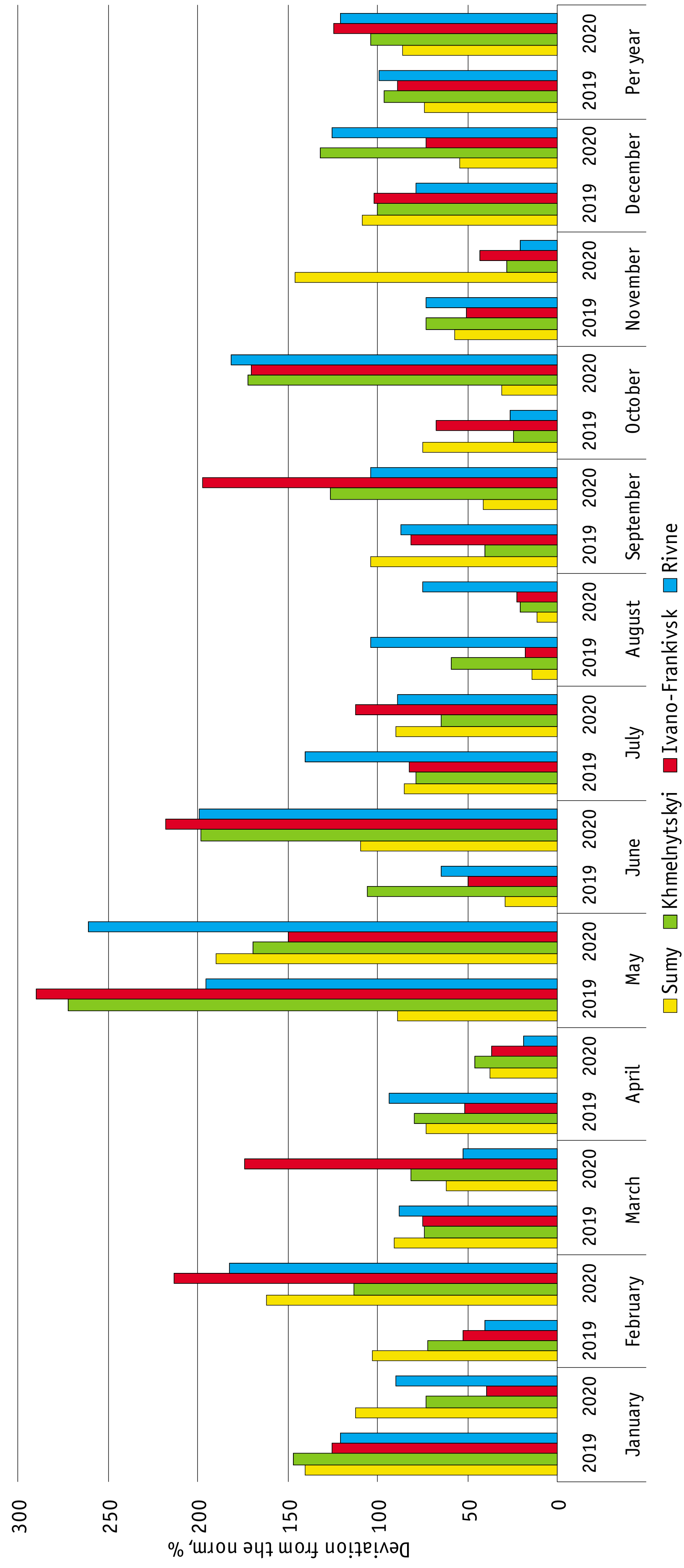

Fig. 3. Precipitation amount, deviation from the norm %

Table 2

Grain productivity and quality indicators for winter triticale varieties, average for 2019–2020

Variety	Yield, t/ha		Weight of 1000 grains, g		Nature, g/l	Protein content, %	
	Forest-Steppe	Polissia	Forest-Steppe	Polissia		Forest-Steppe	Polissia
'MIP Yatahan'	4.8	5.1	47.9	42.8	656	**13.3**	**14.3**
'MIP Feniks'	**5.9**	5.1	49.9	**45.3**	**688**	12.3	12.9
'Pamiati Patseky'	5.1	**5.8**	**50.9**	41.6	671	12.9	13.9
'Solodyuk'	5.2	5.5	43.9	35.3	679	12.4	13.8
'Lyubomyr'	5.3	5.2	43.2	33.9	629	12.2	13.7
'Myronosets'	5.3	5.2	41.8	36.7	642	12.4	13.0
$S_{\bar{x}}$	5.3	5.3	46.3	39.3	661	12.6	13.6
V,%	6.4	5.2	8.2	11.7	3.5	3.4	4.0
σ	0.3	0.3	3.8	4.6	22.8	0.4	0.5
$LCD_{0,05}$	0.4	0.3	4.5	5.4	27	0.5	0.6
min	4.8	5.1	41.8	33.9	629	12.2	12.9
max	5.9	5.8	50.9	45.3	688	13.3	14.3

The bigger the grain, the better it is filled, the higher the numerical value of the weight of 1000 grains. A poorly filled grain has a shrivelled endosperm, there may be layers of air between it and the husk, which reduces the weight of 1000 grains. The greater the weight of 1000 grains, the more nutrients it contains. Therefore, the 1000 kernel weight index is important in assessing the quality of the seed grain: the higher it is, the better the quality of the grain and the greater the guarantee of obtaining a large, vigorous plant [12, 32, 33].

The average weight of 1,000 grains of the investigated varieties of winter triticale in the 2019–2020 research years was 46.3 g in the Forest-Steppe zone and 39.3 g in the Polissia zone. The maximum value of the weight of 1,000 grains in the Forest-Steppe zone (50.9 g) was recorded for the variety 'Pamiati Patseky' and in the Polissia zone – 45.3 g for the variety 'MIP Feniks'.

Winter triticale for human consumption has a well filled grain, close to that of wheat, and a good marketable appearance. Grain quality averaged 661 g/l per variety, ranging from 629 g/l for 'Liubomyr' to 688 g/l for 'MIP Feniks'. According to the quality indicators, triticale grain of the winter variety 'MIP Feniks'; with a nature index of 688 g/l belongs to the 1st quality class, grain of the varieties 'Solodiuk', 'Pamiati Patseky' and 'MIP Yatahan' with a grain nature index of 679–656 g/l belongs to the 2nd quality class, which is recommended for food use. Cereals with a grain nature index < 650 g/l ('Myronosets' and 'Liubomyr') belong to the 3rd quality class, which is not regulated and is recommended for feed and technical needs.

The protein content of winter triticale varieties was 12.6% on average for the 2019–2020 research years in the Forest-Steppe zone and ranged from 12.2% ('Liubomyr') to 13.3% ('MIP Yatahan'), according to the classifier corresponded to grain of average quality. The coefficient of variation (V,%) for this characteristic was 3.5%, so the population is homogeneous, the average is typical, the variation is considered low. In the Polissia zone, the protein content of the varieties averaged 13.6% over the years of research and ranged from 12.9% – medium content ('MIP Feniks') to 14.3% – high content ('MIP Yatahan'). The within-zone variation was low and amounted to 4.0%.

Climate change affects crop yields in different ways due to rainfall and temperature extremes. Abnormal events – such as unusually low temperatures in autumn or intense heat in spring – can lead to significant losses in winter triticale crops. Climate change may have a positive impact on agriculture through higher winter temperatures and increased winter precipitation, as well as a longer frost-free season.

The results of the determination of correlation dependencies between the studied traits by zones in the grain of winter triticale varieties are ambiguous. A different response of the varieties to the zonal growing conditions was observed (Table 3).

Table 3

Correlations between the studied winter triticale traits by zones

Indexes	∑R		Yield, t/ha		Weight of 1000 grains, g		Protein content, %		Nature, g/l
	Forest-Steppe	Polissia	Forest-Steppe	Polissia	Forest-Steppe	Polissia	Forest-Steppe	Polissia	Polissia
$\sum t_{act > 10}$	**0.33**	–0.29	–0.13	**0.33**	–0.02	0.01	0.11	–0.49	–0.22
∑R			**0.66**	**0.34**	0.08	–0.06	**–0.56**	**0.56**	0.14
Yield, t/ha					0.10	–0.12	**–0.74**	**0.32**	**0.30**
Weight of 1000 grains, g							**0.50**	–0.07	**0.61**

It was found that in the Forest-Steppe zone there is a direct positive relationship (r = 0.33) between the sum of active temperatures and the amount of precipitation during the same period. However, in the Polissia zone, the opposite dependence is observed (r = −0.29). This phenomenon can be explained by the difference in the number of litterfalls; on average, precipitation in the Forest-Steppe zone was 5% less than in the average multi-year data, and 15% more in the Polissia zone.

The index of the sum of the active temperatures is positively correlated with the grain yield in the Polissia zone (r = 0.33) and inversely correlated with the protein content in the grain (r = −0.49). This means that as the active temperature factor increases, the grain yield increases and its protein content decreases.

The positive dynamics of the influence of the rainfall factor during the growing season on the yield of winter triticale in both growing zones (r = 0.66 and 0.34 units) and an increase in the protein content of grain grown in the Polissia zone (r = 0.56) were revealed. However, an increase in precipitation in the Forest-Steppe zone led to a decrease in protein content of the grain (r = −0.56).

Between the productivity factor and the content of protein and nature in the grain grown in the Polissia zone, an average positive correlation was found (r = 0.32 and 0.30 units, respectively), i.e. with an increase in grain yield, the protein content and nature of the grain increased. However, in the Forest-Steppe zone, as the yield increased from 5.3 to 5.9 t/ha, the protein content of the grain decreased from 12.3 to 12.2% (r = −0.74).

An increase in the weight of 1000 grains in the Forest-Steppe zone from 47.9 to 50.9 g predicts an increase in the protein content of the grain (r = 0.50), whereas in the Polissia zone an inverse relationship was found between these indicators (r = −0.07).

A positive average correlation (r = 0.61) was found between the weight of 1000 grains and the nature of the grain, i.e. an increase in the weight of 1000 grains from 41.6 to 45.3 g can lead to an increase in the nature of the grain to 671–688 g/l.

Using the method of correlation-regression analysis, we have determined the direction and magnitude of changes in grain productivity and protein content in winter triticale varieties when the parameters of the sum of active temperatures and the sum of precipitation during the growing season change. R^2 is the coefficient of determination, which determines the proportion of variation in one of the variables that is explained by the variation in another variable. In this case, R^2 = 0.58 and 0.17 units, i.e. 58% and 17% of the variation in yield and 1000 grain weight respectively can be explained, or 58% and 17% of the variability in yield and 1000 grain weight respectively can be explained by the difference in the sum of active temperatures during the vegetation period. The remaining 42% and 83% are explained by the influence of other factors (Figs. 4, 5).

According to the results of the correlation analysis, a strong direct relationship (r = 0.76) was established between grain yield and the sum of active temperatures during the growing season, as well as an average relationship (r = 0.41) between the weight of 1000 grains and the sum of active temperatures during the growing season.

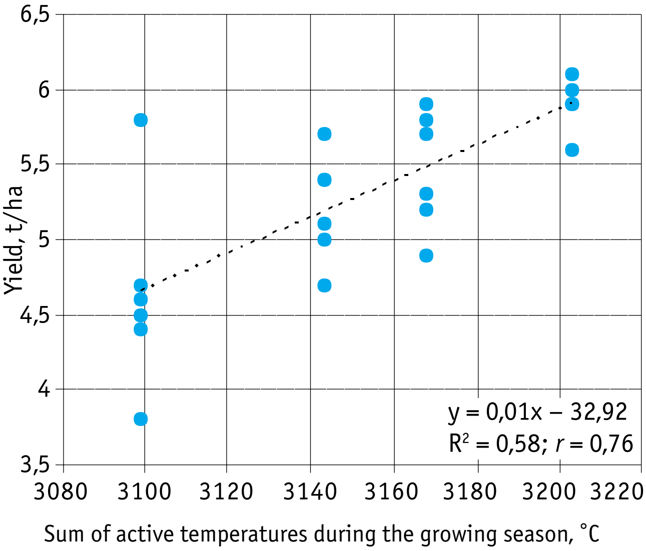

Fig. 4. Scatter plot and dependence of grain yield on the sum of active temperatures during the growing season

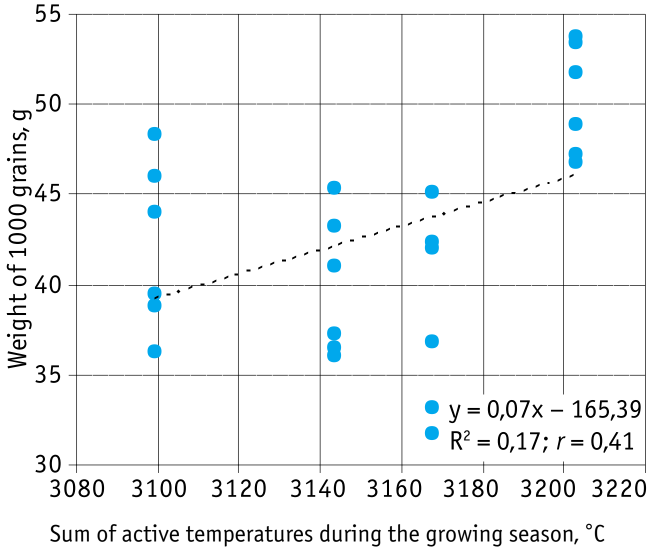

Fig. 5. Scatter plot and the dependence of the weight of 1000 grains on the sum of the active temperatures during the growing season

The regression line confirms that by increasing the sum of active temperatures during the growing season to 3203 °C mm, it is possible to increase the productivity indicators and the weight of 1000 grains from 5.6 to 6.1 t/ha and from 46.8 to 53.5 g, respectively. Under favourable conditions, triticale has a high yield potential and the ability to maximise it.

According to the results of research by a number of scientists, a significant variability of crop productivity has been observed depending on the availability of water and the distribution of rainfall during the growing season, but no significant effect on the productivity indicator was found [2, 34]. According to our calculations, a weak ($r = -0.06$) and medium ($r = -0.67$) inverse relationship was found between the variables yield, weight of 1000 grains and the amount of rainfall during the growing season (Figs. 6, 7). The coefficient of determination between yield, 1000 grain weight and rainfall during the growing season was R^2 = 0.00 and 0.44 units respectively. This means that the rainfall factor had no significant effect on yield (there is no dependence) and the influence of the rainfall factor on the weight of 1000 grains was 44%. The regression line shows that with an increase in the amount of rainfall during the growing season to 515.1 mm, a decrease in the weight of 1000 grains from 38.1 to 45.2 g is possible.

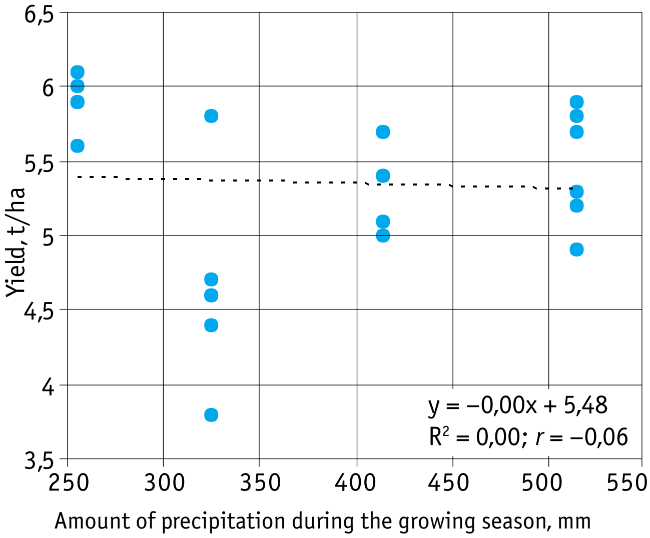

Fig. 6. Scatter plot and dependence of grain yield on the amount of precipitation during the growing season

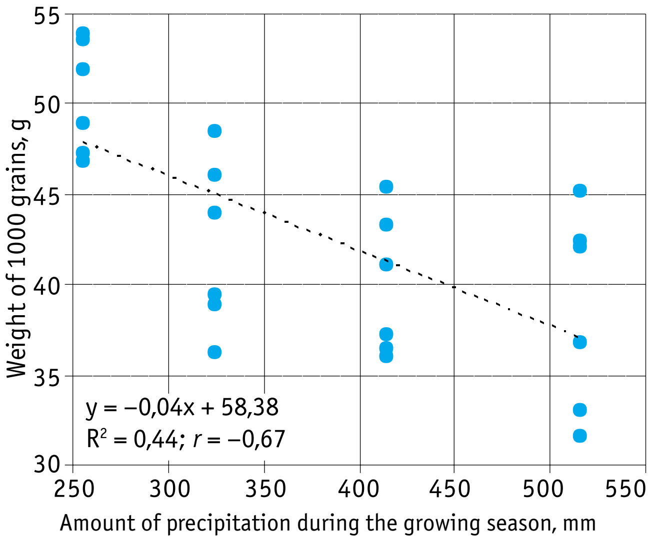

Fig. 7. Scatter plot and the dependence of the weight of 1000 grains on the amount of precipitation during the growing season

Thus, it can be concluded that the amount of active temperatures during the vegetation period has a 58% influence on the production of winter triticale grain yield, the amount of precipitation during the vegetation period has a 44% influence on the formation of the mass of 1000 grains.

The correlation coefficient between the protein content variables and the sum of active temperatures during the growing season showed a weak dependence ($r = 0.14$), as well as an average dependence with the sum of precipitation ($r = 0.39$) (Figs. 8, 9). The coefficient of determination between protein content, the sum of active temperatures and the sum of precipitation during the growing season was R^2 = 0.02 and 0.15 units, respectively. This means that the factor of the sum of the active temperatures influences the protein content in the seeds by only 2% and the sum of the precipitation by 15%. The theoretical regression line shows that with an increase in the sum of active temperatures and precipitation during the growing season from 3167.65 to 3202.9 °C and from 413.85 to 515.1 mm, respectively, it is possible to increase the protein content in grain from 12.4 to 13.8%.

The regression line between the variables grain protein content, yield and weight of 1000 grains confirmed a weak ($r = -0.15$ and -0.18) inverse relationship between the indicators (Figs. 10, 11). The coefficient of determination between protein content, yield and 1000 kernel weight was R^2 = 0.02 and 0.03 units respectively. This means that the factors yield and weight of 1000 kernels do not have a significant influence on the protein content of the kernels (2 and 3% respectively).

The regression line shows that by increasing yield and 1000 grain weight from 5.8 to 6.1 t/ha and from 51.8 to 53.8 g, the protein content in grain can be reduced from 13.1 to 12.0%.

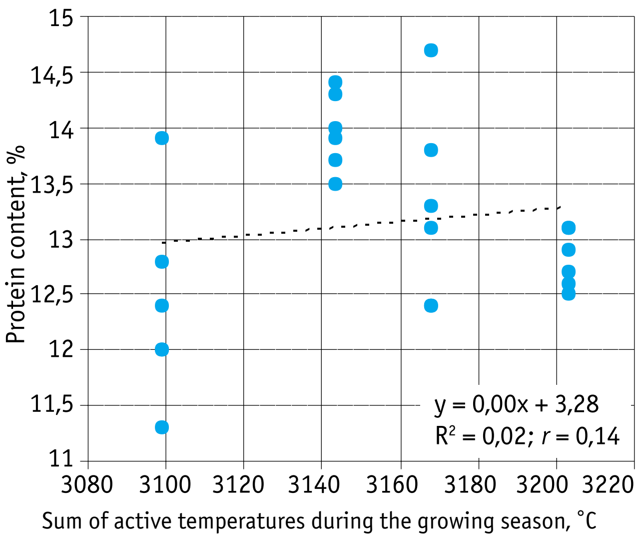

Fig. 8. Scatter plot and dependence of protein content on the sum of active temperatures during the growing season

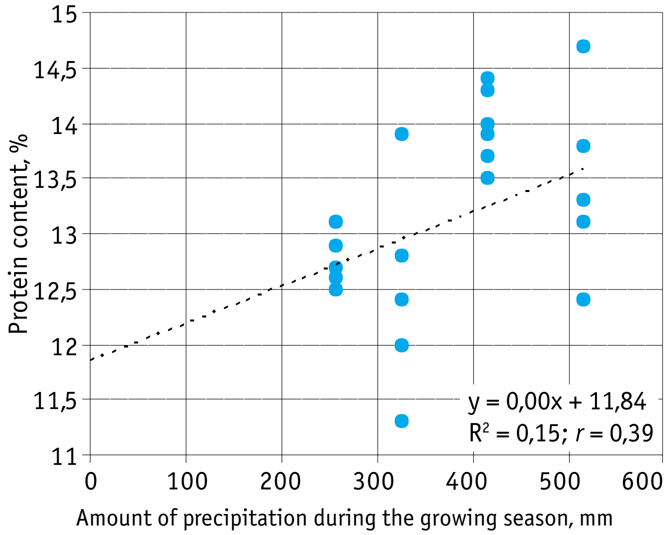

Fig. 9. Scatter plot and dependence of protein content on the amount of precipitation during the growing season

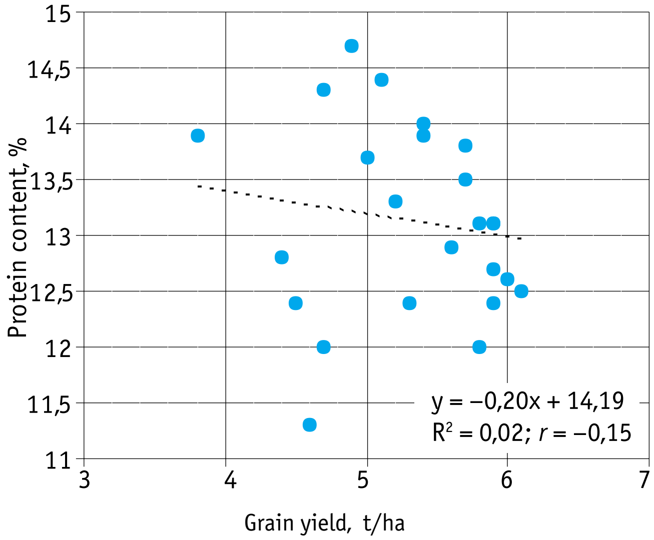

Fig. 10. Scatter plot and dependence of protein content on grain yield

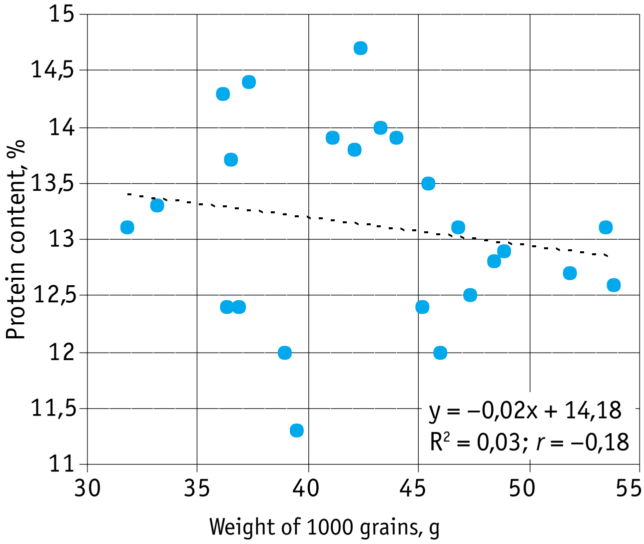

Fig. 11. Scatter plot and dependence of protein content on weight of 1000 grains

Conclusions

Using correlation-regression analysis, it was found that the weather conditions of the year influence the development of productivity and protein content in the grain of winter triticale varieties. The protein content of the grain is a characteristic that depends on the varietal characteristics and the meteorological conditions during the growing season. Winter triticale varieties adapted to local soil and climatic conditions have a high yield potential and the ability to maximise it by producing grain with good technological indicators.

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Мета. Оцінити продуктивність та якість зерна сортів тритикале озимого, вирощуваного в різних ґрунтово-кліматичних умовах. **Методи.** У процесі досліджень використовували лабораторний, розрахунковий і статистичний методи, для підготовки висновків – аналізу та синтезу. **Результати.** Виявлено суттєву зміну ГТК (IV–X) щомісячно, щорічно і загалом по локаціях проведення досліджень. Визначено, що врожайність сортів тритикале озимого в зонах Лісостепу й Полісся становила 5,3 т/га. Максимальні її показники в лісостеповій зоні отримано для сорту 'МІП Фенікс' (5,9 т/га), у поліській – для 'Пам'яті Пацеки' (5,8 т/га). Середній уміст білка в зерні досліджуваних рослин за 2019–2020 рр. у Лісостепу становив 12,6% (від 12,2% у сорту 'Любомир' до 13,3% у 'МІП Ятаган'), що, за класифікатором, відповідає зерну середньої якості, придатному для використання в кондитерській промисловості. Коефіцієнт варіації (V,%) за цією ознакою – 3,5%. Усереднена кількість білка для вирощуваних на Поліссі сортів тритикале озимого – 13,6% (від 12,9% у 'МІП Фенікс' до 14,3% (високий уміст) у 'МІП Ятаган'). Варіація в межах зони становила 4,0% – слабка. Кореляційно-регресійним аналізом встановлено, що збільшення суми активних температур до 3203 °С у період вегетації може спричинити підвищення показників урожайності та маси 1000 зерен із 5,6 до 6,1 т/га та з 46,8 до 53,5 г відповідно; збільшення суми опадів у період вегетації до 515,1 мм призводить до зменшення маси 1000 зерен із 45,2 до 38,1 г; за умови підвищення суми активних температур і кількості опадів під час вегетації з 3167,65 до 3202,9 °С та з 413,85 до 515,1 мм можливе збільшення вмісту білка в зерні з 12,4 до 13,8%; у разі збільшення врожайності й маси 1000 зерен із 5,8 до 6,1 т/га та з 51,8 до 53,8 г відповідно вміст білка в зерні може зменшуватися від 13,1 до 12,0%. **Висновки.** Встановлено різну реакцію сортів на зональні умови вирощування. Виявлено позитивний вплив фактору кількості опадів у період вегетації на врожайність тритикале озимого в Лісостепу та на Поліссі (r = 0,66 та 0,34 одиниці), а також на збільшення вмісту білка в зерні рослин, вирощених на Поліссі (r = 0,56).

Ключові слова: *злаки; харчова цінність; гідротермічний коефіцієнт; урожайність; вміст білка; кореляційно-регресійний аналіз.*

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