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PHENOLOGICAL DEVELOPMENT AND GRAIN YIELDS FOR TRITICALE VARIETIES IN CENTRAL SOUTHERN BULGARIA

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Abstract

The phenological development and grain yield of triticale varieties of different originated were studied in a three-year field experiment for the period 2019-2022. Based on the De Martonne Drought Index, the conditions of the growing seasons were characterized. The dates of the occurrence of the main stages of plant development were recorded, and the interphase periods were characterized based on the number of days with an active temperature above 5°C, the sum of the active temperature, the average temperature, and precipitation. Correlational dependences between grain yield and meteorological parameters during the interphase periods were found. The functional relationship between the amount of precipitation and grain yield was described using mathematical models thus, the grain yield can be predicted. The effects of the environment and the interaction between the varieties and the environment on grain yield were confirmed. The most productive varieties among the tested ones were shown.

***Key words**: phenological development, grain yields, triticale.*

INTRODUCTION

Triticale (×*Triticosecale* Wittm.) is a crop with high potential for grain and biomass yield and high ecological plasticity. The triticale has demonstrated its ability to withstand harsh dryland conditions (Kankarla et al., 2020). Bulgarian triticale varieties have a high genetic potential for grain yield (Baychev & Stoyanov, 2019; Stoyanov, 2021; Stoyanov et al., 2022a; Stoyanov et al., 2022b).

Several studies have demonstrated a relationship between grain yield and specific phenological periods. Guo et al. (2018) have found a close relationship between grain yield and the length of the pre-flowering interphase period in which the ear forms. Uspenskaja et al. (2018) have confirmed that the most important traits associated with grain yield and grain fullness in winter triticale is the duration of the growing season, which consists of the duration of the interphase periods. In recent years, the acceleration of phenological phases and changes in their occurrence and duration have been reported (Kalbarczyk, 2009). Xiao et al. (2021) noted that changes in crop phenology are closely related to regional climate variability.

The biology of cereal crops is related to the particular requirements for temperature, light and moisture, during the growth phases and development stages (Chanev & Filchev, 2021). Because meteorological factors vary in geographical areas, cultivars have different levels of production. To achieve high grain production, the response of varieties to different agro-meteorological conditions should be considered, and cultivation should be localized in specific areas. One study showed a significant relationship between soil conditions and the growth, physiology, and yield of triticale (Habib-ur-Rahman et al., 2022).

Phenological studies of triticale in Bulgaria are scarce. Several studies have analyzed a small number of varieties in individual locations (Kirchev et al., 2010; Kirchev & Muhova, 2018; Krusheva, 2021).

The purpose of this study was to observe the phenological development of triticale varieties under the conditions of Central South Bulgaria and to evaluate grain yield.

MATERIALS AND METHODS

The experimental work was carried out in the period 2019-2022 at the Institute of Field Crops, Agriculture Academy (Bulgaria). The object of this study was eight Bulgarian varieties of triticale: Kolorit (standard), Akord, Borislav, Blagovest, Doni-52, Dobrudzhanets, Irnik, and Lovchanets, and two originating in Poland: Avocado and Casino. The field trial was carried out on Pelic Vertisols, under non-irrigated conditions without fertilization. A block method was used with an experimental plot size of 1.20/8.30 m and three repetitions of the variants. Seeds were sown at 550 germinating seeds/m^2 as follows: October 23, 2019, November 5, 2020, and November 15, 2021.

The phenological phases were registrered according to the BBCH scale (Zadoks et al., 1974), according to which the first number indicates the main stage of growth (0-9) and the second is the secondary growth stage (0-9) (Meier, 2018). The following codes were used to note phenological phases: sowing (00), emergence (09), 3th leaf (13), tillering (21), stem elongation (31), spike emergence (49), first anthers visible (61), late milk (77), soft dough (85) and fully ripe (92). The beginning of the phase was recorded visually when it occurred at 10% of the plants. A destructive method was used to record the phase from germination to stem elongation. Ten plants for each variety were taken from two replicates, and the percentage at which the phase occurred was calculated as the total. The interphase period represents the time from the start of the previous phase until the start of the next phase. These periods are characterized by the following traits: number of days with active temperatures above 5°C (x_1); sum of active temperatures (Σ t $_{act.}$°C) for the period (x_2); mean temperature (t $_{aver.}$°C) calculated as the ratio of Σ t $_{act}$.°C and number of days with an active temperature above 5°C (x_3); amount of precipitation over the duration of a period (x_4).

Harvesting was performed using a small-calibre harvester in a fully ripe state and the grain yield in kg/ha was recalculated.

The average daily temperature and precipitation data were obtained from a weather station (National Institute of Meteorology and Hydrology) located in the experimental field of the institute (42°12'52", N 25°16'57" E).

Weather conditions during the growing season were evaluated using the De Martonne drought index (Faragó et al., 1989). The following formula was used:

$$I_{DMI} = \frac{P}{T + 10},$$

where: I_{DMI} - De Martonne drought Index; P - amount of precipitation for the growing season; T - average daily air temperature.

A statistical grouping of the data was performed. Mathematical methods were used for data evaluation and processing. The processing of the information was done with Statistica 13. The Biostat statistical program was used to perform an analysis of variance (Penchev et al., 1989-1991). The means were compared for significance using the least significance difference (LSD) test at p = 5.0, p =1.0, and p =0.1%. Correlation regression analysis was applied to investigate grain yield trends. This analysis helps determine changes over time in the dependent variable (y) using a linear regression equation:

$$y = a + b x,$$

where: y - grain yield; x - independent variable; a, b - parameters of the equation.

RESULTS AND DISCUSSIONS

The meteorological conditions during the study periods were compared with the long-term period of 1991-2021 (Figure 1). The three growing seasons are warmer and wetter. During the periods 2019-2020, 2020-2021 and 2021-2022, the temperature sums were higher, respectively by 339.0, 230.9 and 165.5°C, as well as the amount of precipitation, by 23.2, 51.8, and 74.8 mm. The De Martonne drought index values for 2019-2020, 2020-2021 and 2021-2022 are 22.3, 24.3 and 26.5, respectively. This index characterizes the climatic conditions in the first period as Mediterranean, and in the other two periods, the conditions were semi-humid. According to Royo et al. (1999), genotypic variability is primarily associated with plant phenology. The graphs represent the varietal characteristics of the meteorological parameter averages for the periods. The period from sowing to emergence did not differ according to the duration (Figure 2). This is determined by equal hydrothermal requirements for germination and emergence, and subsequently the development to the beginning of the light stage. Similar observations for triticale have been described by other authors (Kirchev et al., 2010; Kirchev & Muhova, 2018; Stefanova-Dobreva, 2021; Muhova, 2021).

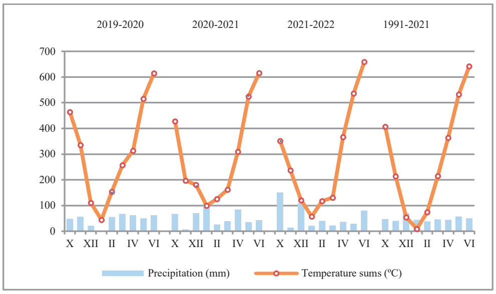

Figure 1. Weather conditions during the growing seasons in triticale and referent period

The Kolorit variety passed the tillering-stem elongation period for the shortest time (40 days). This has also been reported in another study (Stefanova-Dobreva, 2021). For the Avocado variety, the shortest period of spike emergence-first anthers visible was established (6.7 days) and longest stem elongation-spike emergence (22.7 days). For the Casino variety, the longest periods of tillering-stem elongation (45.6 days) and first anther visible-late milk (21 days) were characteristic. The Bulgarian variety Blagovest differed in the shortest duration of late milk-soft dough (14.7 days) and soft dough-fully ripe (7 days). The Casino variety reached full ripening for the longest period of ten days after the beginning of soft dough.

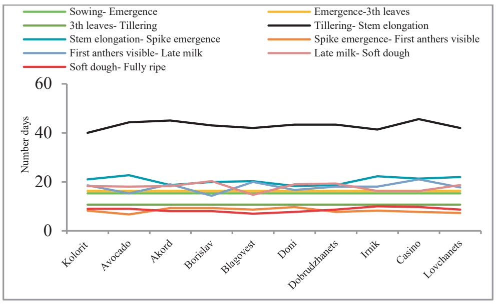

Figure 2. Duration of interphase periods on average for the varieties (2019-2022)

The temperatures were equal from sowing to tillering for all cultivars, as shown in Figure 3. This can be explained by the simultaneous occurrence of the phenological phases. Remarkable differences are visible in this parameter during the stages of spike emergence-first anthers visible, first anthers visible-late milk, and soft dough-fully ripe. For Kolorit and Dobrudzhanets, the lowest temperature sums during tillering-stem elongation and stem elongation-spike emergence were calculated to be 379.3°C and 259.0°C, respectively. The sum of the temperatures from stem elongation to spike emergence for the Avocado variety was the highest (308.5°C) and for Casino, it was the lowest (92.6°C).

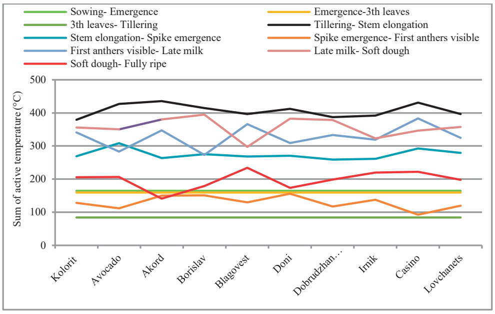

Figure 3. Temperature sum during interphase periods for the varieties (2019-2022)

The mean temperature showed a smooth dynamic within cultivars after phase of stem elongation to soft dough, as shown in Figure 4. The lowest average temperature during stem elongation-spike emergence (13.9°C) was determined for the Kolorit variety. Similarly, for Blagovest and Irnik varieties, the lowest average temperatures were recorded in four interphase periods, namely: for Blagovest during spike emergence-first anthers visible (15.2°C) and soft dough-fully ripe (23.0°C); for Irnik variety during stem elongation - spike emergence (13.9°C) and first anthers visible-late milk (17.5°C). The highest average temperatures respectively, 15.0 and 18.7°C were calculated for the Doni variety during stem elongation-spike emergence, and first anthers visible-late milk, respecively. The Casino variety passed through two periods with the highest average temperature - 17.3 and

21.1°C spike emergence-first anthers visible and late milk-soft dough, respectively.

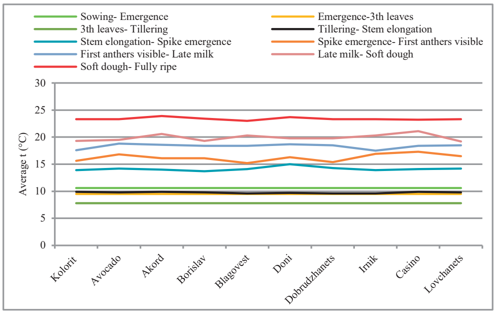

Figure 4. Average temperature during interphase periods for the varieties (2019-2022)

In the 3th growing season, different distributions of rainfall during the interphase periods were registered (Figure 5). During the critical period of spike emergence-first anthers visible, the least amount of precipitation was recorded for the Kolorit, Blagovest and Dobrudzhanets varieties. The highest amount of precipitation (13.6, 31.2 and 25.4 mm) was found for the Casino variety in three interphase periods: spike emergence-first anthers visible, first anthers visible-late milk and soft dough-fully ripe, respectively.

A characteristic of the average values of the meteorological parameters during interphase periods is shown in the following tables.

The average temperature and humidity of the soil layer are determinative factors for emergence. It is necessary for the seeds to absorb water of about 50-60% of their mass, to be able to imbibe and sprout. Zartash et al. (2020) have indicated an optimum temperature from germination to emergence in wheat of 24.0-28.0°C, referring to data from Porter & Gawith (1999).

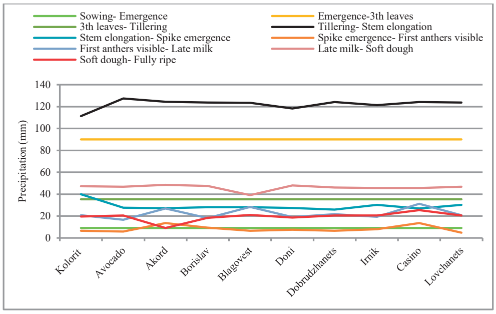

Figure 5. Precipitation during interphase periods for the varieties (2019-2022)

This first period of organogenesis is important because timely germination plays a key role in the formation of primary and secondary root systems and subsequently overwintering through tillering. The period from sowing to emergence had a duration 13-17 days under $t_{aver.}$ 8.3-14.5°C (Table 1). The conditions most favorable for rapid emergence were those in 2021-2022, when the amount of precipitation was 9.7 mm, $t_{aver.}$ 8.9°C. Variation on $\Sigma t_{act.}$, $t_{aver.}$ and precipitation was found for this period, according to the values of the coefficients of variation, 42.9, 32.1 and 59.1%, respectively.

Table 1. Characteristics of the meteorological traits during period of sowing - emergence average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	R	St. D.	CV%
x_1	17	16	13	13	17	15.3	4	2.1	13.7
x_2	245.8	132.7	115.8	115.8	245.8	164.8	130.0	70.7	42.9
x_3	14.5	8.3	8.9	8.3	14.5	10.6	6.2	3.4	32.1
x_4	14.1	3.4	9.7	3.4	14.1	9.1	10.7	5.4	59.1

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4-amount of precipitation.

The next interphase period of emergence-3th leaf has an average duration of 16.3 days, a sum of 159.5°C active temperature, $t_{aver.}$ 9.5°C and 90.0 mm of precipitation, according to Table 2. The shortest was the period in 2020-2021, when $\Sigma t_{act.}$ and $t_{aver.}$ are the lowest 91.4 and 7.0°C, respectively. Variations on $\Sigma t_{act.}$, and precipitation were found based on CV-39.8% and 37.0%, respectively.

Table 2. Characteristics of the meteorological parameters during period of emergence -3 th leaves average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	18	13	18	13	18	16.3	5	2.9	17.8
x_2	217.2	91.4	169.8	91.4	217.2	159.5	125.8	63.5	39.8
x_3	12.1	7.0	9.4	7.0	12.2	9.5	5.2	2.6	27.4
x_4	69	72.5	128.4	69.0	128.4	90.0	59.4	33.3	37.0

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4-amount of precipitation.

From Table 3, is obvious that the period of 3th leaf-tillering continued on average 10.7 days, Σ t act. are 84.2°C, a recorded precipitation of 35.3 mm. A wide variation in the duration of this period was found (CV=53.3%). This explains the variation on Σ t act. (CV = 55.5%) and precipitation (CV = 128.6%). The shortest period for the varieties was in 2021-2022, when the temperature sum was the lowest (44.7°C) and the precipitation was the least (0.4 mm). t aver. shows similar values across periods.

Table 3. Characteristics of the meteorological traits during period of 3 th leaves - tillering average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	9	17	6	6	17	10.7	11	5.7	53.3
x_2	72.2	135.8	44.7	44.7	125.8	84.2	91.1	46.7	55.5
x_3	8.0	8.0	7.5	7.5	8.0	7.8	0.5	0.3	3.8
x_4	19.0	86.6	0.4	0.4	86.4	35.3	86.2	45.4	128.6

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4- amount of precipitation.

During the period of tillering-stem elongation (43 days) the average recorded temperature sum was 410.0°C, the fallen prrcipitation was 22.2 mm, and t aver. Was 9.7°C (Table 4). The average duration for the varieties was the largest in 2020–2021 (52.1 days) and the recorded precipitation was the most (170.3 mm). In 2021-2022 the interphase period continued in the shortest time due to the lowest amount of precipitation (75.7 mm) and highest average temperature (11.5°C), which are premises for accelerating development. The most variable is precipitation (CV = 32.8%) (Figure 5). At the end of tillering, the light stage begins in cereal plants, during which the daily air temperature gradually increases under the influence of the lengthening of the day.

Table 4. Characteristics of the meteorological traits during period of tillering-stem elongation average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	43.2	52.1	33.7	32	56	43	24	8	18.6
x_2	339.0	465.7	385.1	379.0	513.2	410.0	194.2	48.3	11.8
x_3	8.8	8.9	11.5	8.7	12.0	9.7	3.3	1.3	13.2
x_4	120.6	170.3	75.7	75.4	172.1	122.2	96.7	40.1	32.8

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4-amount of precipitation.

According to Table 5, stem elongation-spike emergence is the second longest period, during which the meteorological parameters duration and precipitation are characterized by a large heterogeneity within cultivars, as described in Figure 3, Figure 6, and according to CV - 37.7% and 101.7%, respectively. They have reported similar observations for varietal differences in the duration of the period of emergence - flowering in 12 winter wheat cultivars (Rezaei et al., 2018). The period 2021-2022 was the shortest (15 days), and the lowest Σ t $_{act.}$ (218.0°C), but the highest t $_{aver.}$ (17.7°C) were recorded. The short interphase periods in 2020-2021 and 2021-2022 correspond to later sowing dates. Svystunova et al. (2020) have reported similar observations in triticale phenology, as well as differences in the duration of this period within varieties. CV values of 37.7% and 101.7% respectively, for the duration and the precipitation, determine strong variation from the mean.

Table 5. Characteristics of the meteorological traits during period of stem elongation-spike emergence average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	30.6	16	15	12	36	20.5	24	7.7	37.7
x_2	336.6	258.4	218.0	145.1	386	267.7	240.9	64.4	24.1
x_3	10.0	16.2	17.7	10.5	16.6	14.0	6.1	2.2	15.7
x_4	68.3	0.6	21.0	0.6	99.7	29.3	99.1	29.8	101.7

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4-amount of precipitation.

The shortest period of spike emergence-first anthers visible was in 2021-2022 (7.4 days), under the highest t $_{aver.}$ (18.2°C) and the least precipitation (2.6 mm), due to the accelerated growth rate under dry and warm weather (Table 6). The maximum and minimum duration over the years are 4 and 14 days, as shown in Table 6. Large deviations were established in values for Σ t $_{act.}$ (St. D = 28.7) and amount of precipitation (CV = 82.9%).

Table 6. Characteristics of the meteorological traits during period of spike emergence –first anthers visible average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	9	7.8	7.4	4	14	8.3	10	2.1	25.3
x_2	144.3	120.5	133.7	82.3	210.6	132.2	128.3	28.7	21.6
x_3	14.9	15.5	18.2	13.3	20.6	16.2	7.3	1.8	11.2
x_4	13.3	8.7	2.6	0	23.2	8.2	23.2	6.8	82.9

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4-amount of precipitation.

For the interphase periods of first anthers visible-late milk and late milk-soft dough, a duration of 17.9 days was found, similar values of Σ t $_{act.}$ (328.4 and 356.7°C) and t $_{aver.}$ (18.5 and 19.9°C), but contrasting precipitation conditions (Table 7, Table 8, and Figure 6). The optimal temperature range for flowering and grain filling is 18-22°C. This meteorological parameter is stable during the three study periods (Table 7 and Table 8). Precipitation in 2021-2022 (76.1 mm) increased air moisture and delayed the process of grain filling, resulting in extending the period. CV takes values 54.1 and 47.7% for the two periods.

Table 7. Characteristics of the meteorological parameters during period of first anthers visible-late milk average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	18.3	19.4	15.9	12	27	17.9	15	3.5	19.3
x_2	331.3	337.9	314.9	222.8	477.1	328.4	254.3	51.4	15.7
x_3	18.2	17.5	19.9	16.2	20.6	18.5	4.4	1.2	6.3
x_4	23.1	33.0	10.9	6.6	44.8	22.0	38.2	11.9	54.1

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4- amoun of precipitation.

Table 8. Characteristics of the meteorological traits during period of late milk - soft dough average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	15.8	18	20	11	25	17.9	14.0	3.3	18.4
x_2	288.3	356.1	465.7	222.6	540.0	356.7	317.4	78.1	21.9
x_3	18.4	20.1	21.2	16.9	21.9	19.9	5.0	1.5	7.5
x_4	29.8	32.2	76.1	12.1	80.5	46.0	68.4	22.0	47.7

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4- amount of precipitation.

A fluctuation in the amount of precipitation is also noticeable during soft dough-fully ripe, because over the years 0-50.2 mm, the fallen precipitation was reported respectively, and the CV value is 106.7%. A deviation is visible for duration (CV = 34.7%) (Table 9). The longest was the duration in 2019-2020, when the registered precipitation was 44.2 mm. The grain filling process is accelerating at a higher average temperature, as it is during 2020-2021 (25.5°C), and accordingly the maturation proceeded in the shortest time (5.9 days). Average temperatures over the years are within the optimal range for cereal crops (20-25°C) in moderate climates (Farooq et al., 2011). It is noticeable that precipitation during all interphase periods shows a strong variation.

The biological cycle of plants was shortest in 2021-2022, because maximum average temperature (14.6°C) and minimal precipitation (327.2 mm) were recorded for this period (Table 9). The cumulative active temperature is between 1,984.9 and 2,371.0°C. This result is in accordance with results of Soto et al. (2009) who found that common wheat and triticale require an active temperature sum range of 1,800°C - 2,400°C to complete their biological cycle. A one-year study by Akhlaq et al. (2015) recorded a 161 day growing season for triticale under the influence of fertilization, but it is not specified whether this period is calendar or based on active temperatures. In the study by Krusheva (2021) duration of 231-260 days, $\Sigma\ t_{act.}$ 1,995-2,936°C, $t_{aver.}$ 8.7-12.9°C and precipitation 341-580 mm, were indicated in triticale.

Table 9. Characteristics of the meteorological traits during period of soft dough –fully ripe average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV%
x_1	11.1	5.9	9	4	15	8.7	11	3	34.7
x_2	230.6	150.1	212.9	99.0	343.1	197.9	244.1	58.0	29.3
x_3	20.8	25.5	23.9	20.5	25.7	23.4	5.2	2.1	8.9
x_4	44.2	9.7	4.4	0	50.2	19.4	50.2	20.7	106.7

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4- amount of precipitation.

Results showed that in 2021 (5,560.7 kg/ha) and 2022 (4,568.3 kg/ha), the grain yields were significantly lower compared to 2020 (6,610.7 kg/ha) by 84.1 and 69.1%, respectively (Figure 2A). On Figure 2, is evidence that most varieties have a higher average yield compared to Kolorit variety (5,184.2 kg/ha), except for results, but no significance.

The highest average grain yield demonstrated Avocado (6,181.3 kg/ha), Casino (6,078.6 kg/ha), Dobrudzhanets (5,826.7 kg/ha) and Blagovest (5,728.7 kg/ha). These varieties exceed the control by 19.1, 17.3, 12.4, 10.5, and 9.8%. It was found that the conditions of the year have a significant effect on the yield (η=64.1%), followed by an effect of interaction between varieties and environment (η=17.2%) and variety (η=13.0%) (Table 10). These data show that the cultivars have different ranks over the years, and the average yields for the three periods studied are also different (Figure 6). It should be noted that average yields obtained were highest under Mediterranean conditions in 2020 and lower under semi-humid conditions in 2021 and 2022. Bekish et al. (2020) have also demonstrated a strong influence of year conditions (77.3%) and variety (19.9%) in triticale.

Table 10. Characteristics of meteorological traits during period of sowing-fully ripe average for the varieties and periods

Traits	Periods			Descriptive statistics					
	2019-2020	2020-2021	2021-2022	min.	max.	average	range	St. D.	CV %
x_1	155.2	148.7	138	138	178	158.5	40.0	15.3	9.7
x_2	2,249.7	2,049.0	2,020.4	1,984.9	2,371.0	2,106.5	368.1	115.9	5.5
x_3	13.4	12.4	14.6	12.2	14.7	13.4	2.5	1.0	7.5
x_4	401.4	410.6	327.2	323.1	474.5	379.7	151.4	41.0	10.8

x_1-number of days with active temperatures above 5°C; x_2-sum of active temperatures; x_3-mean temperature; x_4- amount of precipitation.

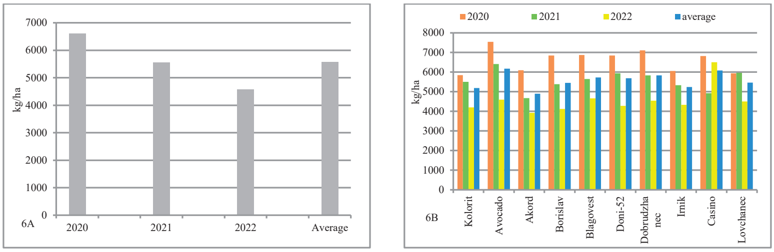

Figure 6. Triticale grain yields by year and average for the period

Correlative and regression dependences were analyzed. In the phase of tillering-stem elongation, the grain yield is strongly negatively correlated with t $_{aver.}$ This negative relationship is visible during all interphase periods, as well as during the period of sowing - fully ripe (Table 12). This can be explained by the conditions for taking the course of physiological processes related to growth, which are dependent on the temperature regime during the interphase periods. “A change in the optimal temperature is considered stress, and the greater the difference, the more the phases will be prolonged or accelerated”

Table 11. Analysis of variance of grain yield

Source	df	Sum of squares	η (%)	Mean square	F	p value
Total	89	9.766272E+07	100			
Block	2	64000	6.553166E-02	32000	0.3365206	0.72052
Variants	29	9.208346E+07	94.3	3175292***	33.39222	0.00000
Variety	9	1.271117E+07	13.0	1412352***	14.85267	0.00000
Year	2	6.25856E+07	64.1	3.12928E+07***	329.0835	0.00000
V×Y	18	1.678669E+07	17.2	932593.8***	9.807406	0.00000
Error	58	5515264	5.6	95090.76		

*** significance at p=0.1%.

(Wahid et al., 2007). This leads to a decrease in yields. Crops that are highly affected by stress attempt to survive and complete all the developmental stages within a shortened period of time (Hakim et al., 2012). Racz et al. (2017) have obtained conflicting results, namely that average temperature during germination and heading-flowering has a strong positive relationship with grain yield in triticale.

Moderate to high positive relationships of yield and precipitation were established for all the periods, except for late milk-soft dough. The quantity of precipitation is closely connected with soil moisture. During the period of tillering- stem elongation, the insufficiency of moisture retards tillers formation (r = 0.403). At the beginning of stem elongation, the reproductive organs are formed and this stage is crucial for future yields (r = 0.529). At the heading the insufficiency of moisture reduces pollination and fertilization, which results in a poorly grainy spike (r = 0.366). After flowering, the growth of the vegetative organs ceases and the need for water is less (r = 0.328).

During the grain filling period, from late milk to soft dough, it is known that the accumulation of dry matter becomes much more rapid at relatively high temperatures (Delogu et al., 2002). Precipitation and high humidity delay ripening and deteriorate grain quality. This is also associated with a decrease in temperature respectively, with the temperature sum. Therefore, a high negative correlation (r= -0.728), resulting in the yield correlates negatively with the other meteorological parameters.

During the two periods of tillering-stem elongation and stem elongation-spike emergence, moderate and significant dependences with positive character were confirmed: 0.430 and 0.678, respectively, of yield with duration. This can be explained by the theory of light stages, namely that for the life cycle of grain plants, it is necessary to extend the length of the day and, accordingly, the temperature.

The relationship between grain yield and precipitation during the period of soft dough-fully ripe is positive (0.640), because the grain is yellow-green and still moving, and deposition of nitrogenous substances and carbohydrates coming from the vegetative parts. The lack of rainfall and high temperatures lead to dehydration of the grain, shortening this period and yield reduction. A positive correlation was found with the grain filling period (r = 0.340), as was also reported by other authors (Wolde et al., 2016). There is data to reduce wheat grain yield from 31 to 35% as a result of drought stress during this period (Farooq et al., 2011). The duration correlated strongest with yield (r = 0.744). The results are in accordance with the findings of other scientists. Brzozowska et al. (2018) have found a significant positive correlation between spring triticale yields and the duration of a growing season and a negative with mean temperature. A study by Korkhova and Mykolaichuk (2022) showed a significant influence of the duration of interphases, vegetation periods, and the amount of precipitation on the grain yield of winter durum wheat.

Table 12. Pearson correlation coefficients between meteorological traits during interphase periods and grain yield

Parameters/Periods	21-31	31-49	49-61	61-77	77-85	85-92	00-92
Grain yield							
x_1	0.430^{**}	0.678^{***}	0.182^{ns}	0.245^{ns}	-0.522^{***}	0.340^{*}	0.744^{***}
x_2	-0.007^{ns}	0.638^{***}	-0.107^{ns}	0.096^{ns}	-0.688^{***}	0.226^{ns}	0.647^{***}
x_3	-0.722^{***}	-0.530^{***}	-0.484^{**}	-0.542^{**}	-0.682^{***}	-0.518^{***}	-0.550^{***}
x_4	0.403^{**}	0.529^{***}	0.366^{*}	0.328^{*}	-0.728^{***}	0.640^{***}	0.576^{***}

n = 30; Significant correlations are indicated by stars ($p < 0.01^{***} < p < 0.05^{**}$)

Based on correlational dependences a regression equations were constructed, that describe the functional connection between grain yield and precipitation. Thus, a grain yield can be predicted (Table 12). According to Table 12, the coefficients of determination (R^2) have the highest value during the periods 77-85 and 85-92 respectively, 0.530 and 0.410, or 53.0% and 41.1% the yield change can be explained by the change from precipitation. The mathematical models and coefficients a and b are adequate at significance level a = 0.05. According to the function, the grain yield will increase by 31.8 when the precipitation increases by 1.0 during the period 85-92. For interphase period 77-85, the grain yield is expected to decrease by 33.9 when precipitation increases by 1.0. Cetin et al. (2022) have established positive effects of rainfall (R^2 = 0.72) on grain yield in heading, anthesis and grain filling of durum wheat.

Table 13. Regression dependences for grain yield and precipitation during interphase periods

Periods	Model	R^2	F crit.	Sign. F	P value Intercept (a)	P value variable (b)
21-31	$Y = 4315.80+10.30968\ x_4$	0.162	5.426	0.027	2.83603E-08	0.027283472
31-49	$Y = 5041.66+18.2102\ x_4$	0.279	10.85	0.003	3.20522E-19	0.002677887
49-61	$Y = 5120.90+ 55.2480\ x_4$	0.134	4.330	0.046	4.73571E-17	0.046707963
61-77	$Y = 4955.89+28.1764\ x_4$	0.108	3.381	0.077	2.31049E-13	0.07655967
77-85	$Y = 7139.63–33.9927\ x_4$	0.530	31.60	5.08743E-06	7.74911E-20	5.08743E-06
85-92	$Y = 4958.40+31.7659\ x_4$	0.410	19.47	0.000	1.86868E-20	0.000137667

According to the R^2 of the remaining models, describe little change in yield, based on the change in precipitation. The equation describing the dependence of grain yield and precipitation during a period 31-49 explains 27.9% of yield values, or at that important period of triticale development when emergence is expected, it is possible to increase the yield by 18.2%, if the precipitation is higher by 1.0.

CONCLUSIONS

This work analyzed the phenological development and productivity of modern varieties of triticale for a three-year period, evaluated the effects of cultivar and location, and characterized the agrometeorological conditions during the growing seasons. Applied analyses found wide variation in precipitation, a negative correlation of yield with average temperature during all interphase periods, and negative dependences of grain yield with the duration of the period, the temperature sum, average temperature, and precipitation, during the period of late milk-soft dough. Functional dependencies between grain yield and rainfall during phenological periods were revealed. Mathematical models describing the relationship between grain yield and precipitation during the periods of late milk-soft dough and soft dough-fully ripe explain the yield change and present the best prognosis. They are defined climatic conditions of growing seasons in which varieties were grown-one in the Mediterranean and two periods under semi-humid conditions. The terms of the year have a large and significant impact on yield. The influence of cultivar-environment interaction as well as cultivar is significant but small. The average for the period with highest yielding varieties are indicated.

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