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YIELD AND STRUCTURAL COMPONENTS OF THE SPIKE OF LOCAL SPECIES OF *Triticum dicoccum* Sch., *Triticum spelta* L. AND *Triticum monococcum* L. IN THE CONDITIONS OF CENTRAL SOUTH BULGARIA

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Abstract

In the period 2018-2021 at the Agricultural University, Plovdiv, Bulgaria, a comparative study was conducted on the productivity of three local species of Triticum dicoccum Sch., Triticum spelta L. and Triticum monococcum L. A block method was used, in four replications, the size of the reporting plot was 10 m^2. The influence of the year and the species on the yield and the structural components of the spike were studied. It has been established that grain yield is formed under the strong and proven influence of the year. There are also proven differences between the yields of individual species (Triticum spelta L. - 2906 kg/ha; Triticum monococcum L. - 2660 kg/ha; Triticum. dicoccum Sch. - 2268 kg/ha). The longest spike forms Triticum spelta L. – 8.2 cm, and the shortest - Triticum dicoccum Sch. – 3.5 cm. The largest number of spikelets formed Triticum monococcum L. (19.2). Triticum. spelta L. has been proven superior in terms of number of grains per spike and grain mass per spike to the other two species.

Key words: spike, *Triticum dicoccum Sch., Triticum monococcum L., Triticum spelta L., yield.*

INTRODUCTION

Triticum monococcum L. (einkorn) and *Triticum dicoccum* Sch. (emmer), along with *Triticum spelta* L. (spelt), are among the earliest cereal crops domesticated by humans (Feldman, 1976; Salamini et al., 2002). Interest in these ancient crops quickly declined after the introduction and spread of *Triticum aestivum* L. and *Triticum durum* Desf., which changed people's eating habits. The new species are high- yielding, easy to harvest and make better quality foods.

However, the ancient wheat species retain their importance as species suitable for cultivation on poorer and abandoned soils, suitable for organic production as well. They have valuable nutritional qualities, high adaptability and resistance to diseases and enemies. They are valuable to researchers as a genetic resource for breeding purposes (Stagnari et al., 2008; Glamoclija et al., 2015; Konvalina et al., 2012).

Triticum monococcum L. is considered to be the most ancient species (Zhukovsky, 1957) and belongs to the group of diploid wheat (2n = 14). It has been cultivated for centuries by many peoples. It has been called "the bread of the Thracians", "the wheat of the pharaohs", "the last food of Christ" (Stamatov et al., 2017).

In Bulgaria, these species was studied in detail by Stranski (1929). The author describes 4 wild and 11 domesticated varieties on the territory of the country, including some endemic ones (var. *bulgaricum,* var. *sofianum*). In the Balkan Peninsula, einkorn came from Southwest Asia, where it was first domesticated around 10500 BCE (Heun et al., 1997; Weiss & Zohary, 2011). The spread to the Balkan Peninsula and then to Western and Northern Europe took place during the Pre-Pottery Neolithic period (Desheva et al, 2014; Laghetti et al., 2009).

Data on the cultivation of the emmer were found as early as 12000 to 9000 BC. According to Konvalina et al. (2008), the centre of origin of this wheat is the Middle East (Iran, Iraq, Jordan, Syria and Palestine), and the wild ancestor *Triticum dicoccum* Sch. is still cultivated there. In the period of ancient civilization, wheat played a very important role in human nutrition (De Vita et al., 2006). In Europe it was cultivated in the Neolithic period (Zapata et al., 2004; Costantini, 1989). In Roman times, besides food, it was also used for religious rites (Zohary & Hopf, 2000).

Today, this crop is grown on larger areas in Italy (Hidalgo & Brandolini, 2014), and in some places in the mountainous regions of the

Balkans, Turkey, the Caucasus, Ethiopia, India, France, Italy and Spain (Harlan, 1981; Hammer & Perrino, 1984; Karagöz, 1996).
Spelt wheat is another species of wheat, also known since ancient times. It is considered the probable ancestor of common wheat. Many authors consider it derived from common wheat, carry the same chromosome set and describe it as its subspecies (*Triticum aestivum* subsp. *spelta* L.) (Aufhammer & Kübler, 1992; Dahlstedt, 1997). Recently, there has been an increase in the area of production of this culture, especially in Austria, Poland, Germany, Switzerland, Czech Republic. The interest in spelt is due to the possibility of growing it in a biological production system and also to the high nutritional value of the grain (Majewska et al., 2007; Sulewska et al., 2008).
Studying the three species of wheat in the conditions of Bulgaria is a challenge for researchers, especially with the local forms and in the conditions of organic production (Atanasov et al., 2020; Zorovski et al, 2020; Zorovski, 2021).

MATERIALS AND METHODS

In order to compare the productivity of local forms of wheat - einkorn, emmer and spelt, in the period 2018-2021, a two-factor field experiment was implemented using the block method, in four replications and the size of the reporting plot was 15 m^2. The influence of the year (Factor A: A_1- 2018/2019; A_2- 2019/2020 and A_3-2020/2021) and the influence of the species (Factor B: B_1 - *Triticum dicoccum* Sch., B_2 - *Triticum spelta* L. and B_3 - *Triticum monococcum* L.) on yield (kg/ha) and spike structural components (spike length, number of spikelets per spike, number of grains and grain mass per spike). The correlation dependences between them were also calculated.
The experiment was carried out at the Agroecological Center of the Agricultural University - Plovdiv, Bulgaria, on alluvial-meadow soils. Vetch was used as an predecessor.
All data were statistically processed with SPSS.9 for Microsoft Windows by Duncan's method, Anova. All values marked with the same letter in the tables are not statistically different from each other.

Vegetation periods during the experimental period take place under specific agrometeorological conditions. The figure for the temperature conditions (Figure 1) shows the recorded significantly higher temperatures than the norm for the whole experimental period, which is in absolute harmony with the global trends of climate change.

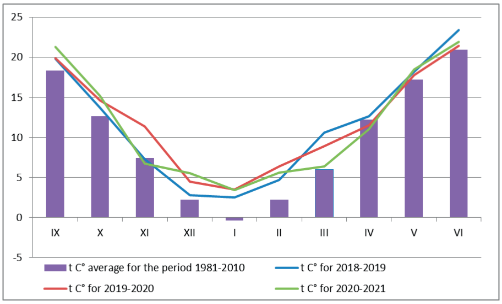

Figure 1. Average monthly temperature (t °C) during the growing seasons, Plovdiv, Bulgaria (2018-2021)

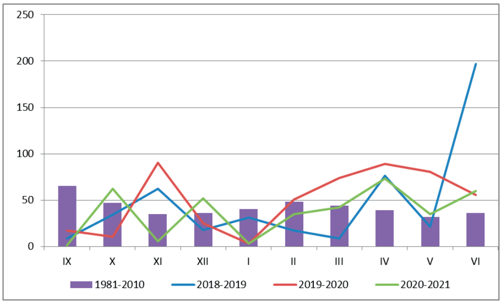

Figure 2. Amount of precipitation (mm/m^2) during the growing seasons, Plovdiv, Bulgaria (2018-2021)

Precipitation was above normal with 52, 74 and 47 l/m^2 for the 6-month growing season, respectively, for the three years (Figure 2). However, they are unevenly distributed. At the beginning of the growing season, with extremely insufficient rainfall in September (Figure 2), soil preparation is very difficult, which affects timely sowing. A certain normalization of the conditions for normal germination and initial development is only in November 2018 and 2019, and in October 2020. A lack of precipitation is also reported in the tillering and stem elongation phases. Above normal rainfall in April to June in all three years, and excessive amounts in June 2019 even created conditions for some laying.

RESULTS AND DISCUSSIONS

Grain yield. When processing the statistical data by year and by species, it is established that the emmer realizes its potential best in the second experimental year, realizing a yield of 2908 kg/ha of grain. This result proved to exceed the yield - in the third (by 12.3%) and especially the first (by 53.7%) experimental year.

Spelt responded to agrometeorological data in years in a similar way. The highest yield was reported again in the 2019/2020 vegetation year - 3647 kg/ha, followed by proven differences from the third and first years (Table 1).

In the case of einkorn, yields in the first and third year are in the same statistical group, but the second year is also the most favourable for this species, with a proven higher yield. It exceeds the first and third year, respectively by 30.9% and by 26.9%.

Table 1. Grain yields of *Triticum dicoccum* Sch., *Triticum spelta* L. and *Triticum monococcum* L. in the years of the study, kg/ha

Year	*Triticum dicoccum* Sch.	*Triticum spelta* L.	*Triticum monococcum* L.
2018/2019	1345 c	1851 c	2276 b
2019/2020	2908 a	3647 a	3295 a
2020/2021	2550 b	3221 b	2409 b

The summarized data on the independent influence of the year and the tested species of wheat on grain yield within the complex two-factor experiment are presented in Table 2.

The year 2019/2020 appears to be the most favourable, in which the average yield for the three species is 3283 kg/ha. The trend for the influence of the year separately for the three types is also preserved in the generalized results for the independent influence of the year, regardless of the wheat species factor. In the third experimental year, a yield of 2660 kg/ha was reported, which is 19% lower than the most favourable second year, and in the first year - 1824 kg/ha - a 44% lower yield.

When comparing the productivity of individual species, regardless of the influence of the year, it is established that for the conditions of Bulgaria, spelt wheat is the most productive, with an average yield of 2906 kg/ha for the three years. With proven differences, it is followed by einkorn (2660 kg/ha) and emmer (2268 kg/ha).

Table 2. Influence of the year and wheat species on grain yields, average for the period 2018-2021, kg/ha

Influence of the **Year**		Influence of the **Wheat species**	
2018/2019	1824 c	*Triticum dicoccum* Sch.	2268 c
2019/2020	3283 a	*Triticum spelta* L.	2906 a
2020/2021	2660 b	*Triticum monococcum* L.	2660 b

Structural elements of the spike in the three tested species**.** The structural elements of the spike are directly related to the productivity of the species. The results of the dispersion analysis of the data related to the main structural components of the spike in the three ancient species, taking into account the influence of the year, are presented in the Table 3.

Table 3. Influence of the year on the main structural elements of the spike in *Triticum dicoccum* Sch., *Triticum spelta* L. and *Triticum monococum* L.

Year	Spike length, cm	Number of spikelets/ spike	Number of grains/ spike	Grain mass/ spike, g
***Triticum dicoccum* Sch.**				
2018/2019	3.1 c	9.6 b	14.1 a	0.53 b
2019/2020	3.8 a	10.2 a	12.6 b	0.56 b
2020/2021	3.5 b	9.7 a	12.8 b	0.66 a
***Triticum spelta* L.**				
2018/2019	7.7 b	13.8 a	21.0 a	1.42 a
2019/2020	8.5 a	13.2 a	17.8 b	1.06 b
2020/2021	8.4 a	13.7 a	19.6 ab	1.22 b
***Triticum monococcum* L.**				
2018/2019	3.9 b	15.4 b	14.4 a	0.53 a
2019/2020	5.2 a	21.5 a	15.4 a	0.47 b
2020/2021	5.1 a	20.7 a	15.4 a	0.51 ab

The length of the spike in the three species is strongly influenced by the conditions of the year (Table 3). The three species tested form very distinct spikes. The longest is the spike of *Triticum spelta* L. - 7.7 cm to 8.5 cm in the three years, shorter are those of *Triticum monococcum* L. - 3.9 to 5.2 cm and of *Triticum dicoccum* Sch. - 3.1 to 3.5 cm.

From the summarized results for the influence of the two tested factors separately (Table 4), it is clear that the second and third years are proven to be superior to the first in terms of this indicator. Spelt developed the longest spike (8.2 cm), followed by einkorn (4.7 cm) and emmer (3.5 cm).

Table 4. Influence of year and species on the main structural components of the spike

Influence of the **Year**		Influence of the **Wheat species**	
Spike length, cm			
2018/2019	4.9 b	*Triticum dicoccum* Sch.	3.5 c
2019/2020	5.8 a	*Triticum spelta* L.	8.2 a
2020/2021	5.7 a	*Triticum monococcum* L.	4.7 b
Number of spikelets/spike			
2018/2019	12.9 b	*Triticum dicoccum* Sch.	10.1 c
2019/2020	15.0 a	*Triticum spelta* L.	13.6 b
2020/2021	14.9 a	*Triticum monococcum* L.	19.2 a
Number of grains/spike			
2018/2019	16.5 a	*Triticum dicoccum* Sch.	13.2 c
2019/2020	15.3 b	*Triticum spelta* L.	19.5 a
2020/2021	15.9 ab	*Triticum monococcum* L.	15.1 b
Grain mass/spike, g			
2018/2019	0.83 a	*Triticum dicoccum* Sch.	0.58 b
2019/2020	0.69 b	*Triticum spelta* L.	1.23 a
2020/2021	0.80 ab	*Triticum monococcum* L.	0.50 c

The number of spikelets per spike ranges from 9.6 to 15.4 in the first year, from 10.2 to 21.5 in the second year, and from 9.7 to 20.7 in the third year.

The most spikelets are formed in the second year (15.0 units on average) (Table 4), followed by the third (14.9 units) and the first year (12.9 units on average). Of the types, eincorn stands out with the highest values of this indicator, followed by spelt and emmer.

The good graininess of the spike can be judged by the next indicator - number of grains in the spike. The analysis of the effect of year shows the inverse trend of number of spikes and spike length. The number of grains per spike in 2018/2019 year is the highest (16.5 pieces) and the lowest is in 2019/2020 year (15.3 pieces). Of the species with the highest values for this indicator, spelt stands out, followed by einkorn and emmer (Table 4).

The weight of the grain of the spike is the final result value that is closest to the harvested yield. Regarding this indicator, the year has a strong proven influence. The heaviest grain was formed in the first experimental year. Of the species, spelt wheat has the heaviest grain (Table 4). Correlation dependencies between spike elements. Grain mass in emmer was moderately strongly positively correlated with grain number, spike number, and spike length (Table 5).

Table 5. Correlation dependencies between main spike parameters in *Triticum monococcum* L. (Coefficient of Correlation - R; Coefficient of Determination - D)

Spike parameters	Grain mass/ spike, g		Number of grains/ spike		Number of spikelets/ spike		Spike length, cm	
	R	D	R	D	R	D	R	D
Grain mass/ spike, g	1.000		0.514 **	26	0.130	2	0.110	1
Number of grains/ spike			1.000		0.665 **	44	0.661 **	44
Number of spikelets/ spike					1.000		0.870 **	76
Spike length, cm							1.000	

The variation of spike productivity is affected in almost the same way (in 17-22%) by the variation of these productive elements of the spike. The number of spikelets strongly depends on the length of the formed spike, and the number of grains in 39% of cases is determined by this number. In emmer, there is a close and always proven relationship between all elements of the spike, but the strongest relationship is between the number of spikelets in the spike and the length of the spike.

In spelt wheat (Table 6) all successively formed elements are in a direct and very strong positive correlation. For example, the length of the spike strongly (in 54% of the cases) determines the number of spikelet developed in the spike, and the number of spikelets is in a very strong and proven correlation relationship (R = 0.719**) with the number of grains formed. The most direct relationship is between the number of grains and their mass, and the dependence in this spike is very strong (R = 0.679**). All factors that influence spike elongation lead to an increase in spike productivity, and this relationship is proven at a significance level of $P \leq 0.01$.

Table 6. Correlation dependencies between main spike parameters in *Triticum spelta* L. (Coefficient of Correlation - R; Coefficient of Determination - D)

Spike parameters	Grain mass/ spike, g		Number of grains/ spike		Number of spikelets/ spike		Spike length, cm	
	R	D	R	D	R	D	R	D
Grain mass/ spike, g	1.000		0.679 **	46	0.464 **	22	0.316 **	10
Number of grains/ spike			1.000		0.719 **	52	0.616 **	38
Number of spikelets/ spike					1.000		0.734 **	54
Spike length, cm							1.000	

In the case of einkorn (Table 7), we find proven dependencies between the grain mass and the number of grains (R = 0.514**), a slightly stronger relationship between the number of grains and the number of spikes (R = 0.665**), and even stronger between the number of spikelet and spike length (R = 0.870**).

There is no direct relationship between grain mass in the spike and the number of spikelet in the spike, nor between grain mass in the spike and spike length.

Table 7. Correlation dependencies between main spike parameters in *Triticum monococcum* L. (Coefficient of Correlation - R; Coefficient of Determination - D)

Spike parameters	Grain mass/ spike, g		Number of grains/ spike		Number of spikelets/ spike		Spike length, Cm	
	R	D	R	D	R	D	R	D
Grain mass/ spike, g	1.000		0.514 **	26	0.130	2	0.110	1
Number of grains/ spike			1.000		0.665 **	44	0.661 **	44
Number of spikelets/ spike					1.000		0.870 **	76
Spike length, cm							1.000	

CONCLUSIONS

The grain yield of the three tested species is most strongly influenced by the agro-meteorological conditions of the years. The highest yield is obtained in the second year (2019/2020 - 3283 kg/ha, which is 54.8% more than the first (the most unfavourable year). Of the three species, *Triticum spelta* L. realizes the highest productive potential - 2906 kg/ha grain yield, followed by *Triticum monococcum* L. - 2660 kg/ha and *Triticum dococcum* Sch. - 2268 kg/ha. The differences between the three species are statistically proven.

Within the experimental period, year appears to be the strongest factor that differentially affects the main components of spike. Greater spike length and a greater number of spikelets per spike have been shown to develop in the second and third experimental years. However, the number of grains, as well as the mass of grains per spike, is the largest in the first (2018/2019) year, followed by the third (2020/ 2021) and the second (2019/2020) years.

The three species also differ significantly from each other in terms of spike components. *Triticum spelta* L. is the leader in terms of spike length, number of grains per spike and grain mass per spike. *Triticum monococcum* L. forms the longest spike, but with the smallest grain mass in it. *Triticum dicoccum* Sch. has the shortest spike, the fewest spikes in it, and the least number of grains per spike. In relation to the grain mass in the spike, *Triticum dicoccum* Sch. proven superior to *Triticum monococcum* L., but proven inferior to *Triticum spelta* L.

The performed correlation analysis proves that the three species have different strong correlative dependencies among themselves. They are most stable with *Triticum spelta* L.

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