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ORIGINAL ARTICLE

Dependence of main shoot ear grain yield from stem deposited ability of winter wheat varieties

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In field conditions, the parameters of deposited ability of the main shoots stem and the remobilization of assimilates of 3 winter wheat varieties of modern breeding (2013-2016) and 3 drought-tolerant ones of earlier breeding (1997-2008) under natural conditions were studied (Kyiv reg., Ukraine). The amount of precipitation for June 2017, during the period of reproductive development of winter wheat, was 34% from normal amount. The comparative estimation showed that the modern variety of Raygorodka and the drought tolerant variety of the earlier breeding Podolianka were the highest grain yield of main shoots ear (respectively, 1.88 ± 0.07 and 1.73 ± 0.05 g) under such conditions. Their yields were higher than other 4 varieties by 5-10%, too. Significant variations in stem dry matter weight, the content and amount of nonstructural carbohydrates in the main shoots, at anthesis, as well as full ripeness there were established between varieties. The strong correlation between the grain yield of main shoot ear with the stem dry matter weight at anthesis (r=0.82 ± 0.29) and difference of stem dry matter weight at anthesis and full ripeness (r=0.84 ± 0.27) was revealed. Both most productive varieties had the highest stem dry matter weight at anthesis, the bigger difference of its weight between at anthesis and the full ripeness and the greater relative contribution of nonstructural carbohydrates accumulated in the stem during period from anthesis to full ripeness in the grain weight it was found. The resistance of winter wheat varieties to drought is due to their ability to depose assimilates in the stem during the preanthesis period (before the grain filling) and due to the re-mobilization of the assimilates accumulated during the reproductive period it has been shown.

Keywords: *Triticum aestivum* L.; drought; grain yield; deposited ability

Introduction

In recent years, in Ukraine during the summer vegetation of winter wheat plants, the air temperature rise and air and soil drought are observed more often. In particular, since the beginning of this century, the amount of precipitation in June and July in about half of years was lower than the norm (respectively, 8 and 10 years out of 17). Wherein, the amount of precipitation in June, when the winter wheat grain filling occurs, in the last three years was only 18-34% of the average long-term values. Winter soft wheat is a drought sensitive culture. The negative effect of water deficit on yield is most pronounced during the periods of flowering initiation, the development of gametophyte, pollination, the formation of grains and their filling (Araus et al., 2002). A drought stress led to decrease in photosynthesis rate and to a smaller formation of photosynthetic assimilates (Medrano et al., 2002; Flexas, 2008). Water stress inhibits chlorophyll synthesis, suppresses and disturbs the reproductive processes of forming of ear's elements, pollen fertility, formation and filling of grains, thereby causing a decrease in number and weight of the grains in the ear (Mahajan, Tuteja, 2005; Nyachiro et al., 2001; Wheat crop, 2008). There are several approaches to solving the problem of obtaining high-yielding drought tolerant wheat varieties. In particular, creating new varieties that, due to longer lengths and strongly branched roots, better use of water (Wasson et al., 2012). However, phenotyping, the research of genetic variability, and mapping of the quantitative trait locus of the root system are rather complex and therefore limited (Atkinson et al., 2015). Other reserves for the improvement of drought tolerance of plants are the genetic diversity of existing varieties and the use of valuable alleles of wild ancestors of wheat (Merchuk-Ovnat et al., 2016; Morgun, 2016). In order to identify marks related to the resistance of winter wheat to drought, comparative studies were carried out on grain productivity of main shoots ear and the deposited ability of its stem in high-yielding modern varieties and earlier breeding varieties with high drought tolerance.

Materials and methods

Experiments were conducted in 2017 at the experimental field of the Institute of Plant Physiology and Genetics of National Academy of Science of Ukraine (50°16'S, 30°19'E; 197 m above sea level). The object of this study was six varieties of winter wheat (*Triticum aestivum* L.): three varieties of the last years breeding (2013-2016): Pridniprovska, Darunok Podillia and Raygorodka and three drought-resistant varieties: Odeska 267, Podolianka and Yednist, which were registered 10-20 years ago (1997-2008). The soil was light-gray, podzolized, light-loamy. The seed rate was 5.5-6 million grains per hectare. During the growing season, 145 kg of nitrogen and 90 kg of phosphorus and potassium per hectare ($N_{145}P_{90}K_{90}$) were added. Agrotechnics and canopy management are generally accepted for this culture in the forest-steppe agro-climatic zone [Morgun et al., 2011]. The accounting area of each of the 4 replications was 10 m^2. The determination of morphometric parameters was carried out on 25 main shoots, and biochemical ones in the mean samples formed from these shoots. Approximately 1 g of each variety was oven dried 2 hours at 105 °C and after at 60 °C to constant weight, for dry mass determination. After full ripeness the grain yield compounds of the main shoots ear (grain weight from ear, number of grains in it, weight of 1000 grains, harvest index) were determined on 25 shoots. The yield was determined by the direct harvesting method in 4 replications. The period of spring and summer vegetation of winter wheat in 2017 was characterized by arid conditions: the amount of precipitation from April to July was lower than the norm, the hydrothermal coefficient was less than 1 (Table 1). The absence of precipitation was observed over 5-7 days (depending on the phase time in some varieties) before anthesis (5-7 June) and 5-7 days after this phase and their insignificant amount (12 mm) to the phase of milk-waxy ripeness (21-23 June). Consequently, during the period of grain filling was observed a drought conditions.

Table 1. Weather conditions of spring-summer vegetation of winter wheat in 2017.

Month	**The average monthly air temperature**		**The monthly amount of precipitation**		**Hydrothermal coefficient, mm/°C**
	°C	deviation from normal	mm	% from normal	
April	10.4	+1.1	25	54	0.82
May	15.2	-0.3	35	61	0.74
June	20.0	+1.5	28	34	0.47
July	20.9	+0.4	62	87	0.96

The estimation of stem deposited ability is carried out by stem dry matter weight at anthesis and full ripeness, as well as by the content or amount of nonstructural carbohydrates in these phases (Ehdaie et al., 2008; Esmaeilpour- Jahromi et al., 2012; Ruuska et al., 2006). The content of nonstructural carbohydrates was determined in the dry matter of main shoots stem. For nonstructural carbohydrate extraction was used 0.5 grams of air-dried and milled sample poured 50 ml of water and filtered. 10 ml of the filtrate and mid-alkaline reagent ($KJsKJO_3$) were poured into the test tubes and placed for 15 min. in boiling water. After cooling, 5 ml of oxalic and sulfuric acid mixtures were added to the test tubes and the amount of copper precipitate was determined (Metody, 1972). After dissolving copper oxide, iodine precipitate was titrated to 0.01 N. solution of sodium thiosulfate in the presence of 0.5 ml of a 0.5% solution of starch until the blue disappears completely. The calculation of nonstructural carbohydrates content was carried out according to Ermakov formula (Metody, 1972). All analyses were performed in triplicate. The gross amount of nonstructural carbohydrates is calculated as the product of their content in the stem and it dry weight (Kiriziy et al., 2011). The contribution rate of accumulated carbohydrates to the grain weight was calculated as the ratio of the difference between a nonstructural carbohydrates gross amount in stem at anthesis and full ripeness to grain weight (Kiriziy et al., 2011). The difference between the treatments was analyzed with Student's *t*-test [15].

Results

The yield of winter wheat varieties in 2017 in both the modern and earlier breeding fluctuated in the near range: respectively, from 7.75-8.55 and 7.75-8.16 t/ha (Table 2). The highest yield among them had varieties Raygorodka (8.55 ± 0.24 t/ha) and Podolianka (8.16 ± 0.18). Other varieties differed insignificantly. However, the modern varieties yield in 2016 was higher. Whereas agrotechnics were the same in both years, the experimental areas were in the same field, higher grain productivity in 2016 could be due to sufficient soil moisture in May due to significantly higher rainfall (146 mm) compared to 2017 (35 mm). In June of both years the amount of precipitation was near (35 and 28 mm).

Table 2. Yield, t/ha, of winter wheat varieties, differing of terms of breeding, in years with varying degree of drought.

Year of breeding	**Variety**	**Yield, t/ha** 2017	2016	**% of 2016**
1997	Odeska 267	7.78 ± 0.15	9.50 ± 0.33	82
2003	Podolianka	8.16 ± 0.18*	9.95 ± 0.41	82
2008	Yednist	7.75 ± 0.27	9.04 ± 0.56	86
2013	Darunok Podillia	7.75 ± 0.16	10.86 ± 0.50*	71
2014	Pridniprovska	7.85 ± 0.34	10.20 ± 0.27*	77
2016	Raygorodka	8.55 ± 0.24*	10.66 ± 0.32*	80

*Note: here and in the tables 3-5: * - indicate significant difference ($p < 0.05$) with the drought -tolerant variety Odeska 267.*

In dry conditions during the period of the formation and filling of grain in 2017, modern varieties reduced yields, compared with 2016, to 71-80% (Table 2). Grain yields of earlier breeding varieties under such conditions decreased to 82-86%. Thus, both the degree of reduction and the yield of modern high-yield varieties under drought conditions remained at the same level as the best drought tolerant varieties. The analysis of components of grain productivity of main shoots ear yield of winter wheat varieties showed that the one of the most yielding variety Raygorodka differed from other in the grain weight per spike (1.88 ± 0.07 g) and their number (48 ± 1 g) (Table 3). The second high-yield variety Podolianka was substantially higher than other varieties by the weight of 1000 grains (47.1 ± 0.5 g). No significant difference in the main shoots ear harvest index was observed between the varieties (Table 3). The drought induced negative changes in the photosynthetic apparatus. Under such condition decreases photosynthetic pigments content, damages the photosynthetic machinery, reduced leaf area and senescence (Fu and Huang, 2001, Wahid et al., 2007, Nyachiroet al., 2001). To order compensate considerable loses in yield, plant may use the remobilization of pre-anthesis assimilates from the stem to a filling of grain. It is believed that even under a moderate drought, the grain filling can depend substantially of the supply of water-soluble carbohydrates rather than on current photosynthetic assimilates (Ehdaie et al., 2006; Slewinski, 2012).

Table 3. The components of grain productivity of main shoots ear yield of winter wheat varieties with different time of breeding.

Variety	Grain weight, g spike^{-1}	1000 grains weight, g	Number of grains spike^{-1}	Harvest index
Odeska 267	1.68 ± 0.09	42.7 ± 1.6	43 ± 2	0.51 ± 0.02
Podolianka	1.73 ± 0.05	47.1 ± 0.5*	41 ± 1	0.52 ± 0.01
Yednist	1.57 ± 0.07	38.0 ± 0.8*	45 ± 2	0.50 ± 0.01
Darunok Podillia	1.73 ± 0.06	44.0 ± 0.9	44 ± 1	0.49 ± 0.01
Pridniprovska	1.73 ± 0.05	45.2 ± 1.0	45 ± 1	0.50 ± 0.01
Raygorodka	1.88 ± 0.07*	44.8 ± 0.8	48 ± 1*	0.52 ± 0.01

One of the deposited ability parameters is the stem dry matter weight of the main shoots. In modern varieties of winter wheat, its value varied in the range from 846 to 1096 mg and almost in the same range in varieties of earlier breeding: from 807 to 1007 mg at anthesis (Table 4). The highest dry matter weight of the stem at this phase had the variety Raygorodka.

Table 4. Stem dry matter weight of the main shoots of winter wheat varieties with different time of breeding at anthesis and full ripeness.

Variety	Stem dry matter weight of the main shoots, mg		Difference between I and II, mg
	at anthesis (I)	at full ripeness (II)	
Odeska 267	955 ± 48	732 ± 38	223 ± 18
Podolianka	1007 ± 21	745 ± 22	262 ± 6*
Yednist	807 ± 33*	672 ± 23	135 ± 15*
Darunok Podillia	991 ± 30	772 ± 37	219 ± 11
Pridniprovska	846 ± 27*	657 ± 31	189 ± 9*
Raygorodka	1096 ± 34*	819 ± 26*	277 ± 12*

The variety Raygorodka had the highest dry matter weight of the stem at full ripeness, a weight of others varieties was 6-20% less. The difference in the stem dry matter weight at anthesis and full ripeness between varieties varied significantly: from 189 mg in variety Pridneprovska to 277 mg in Raygorodka. At the same time, both high yield varieties differed from others in the high difference of stem dry matter weight (Table 4). A significant decrease in the dry matter weight of stem at full ripeness, as compared at anthesis, may indirectly indicate a larger outflow of assimilates from the stem. In the stems of main shoots of these two varieties, high content of non-structural carbohydrates at anthesis was also found: Podolianka -23.5%, Raygorodka - 23.0% (Table 5). The non-structural carbohydrates content at full ripeness for most varieties fluctuated within 4%, for varieties Yednist and Pridneprovska -near 6%.

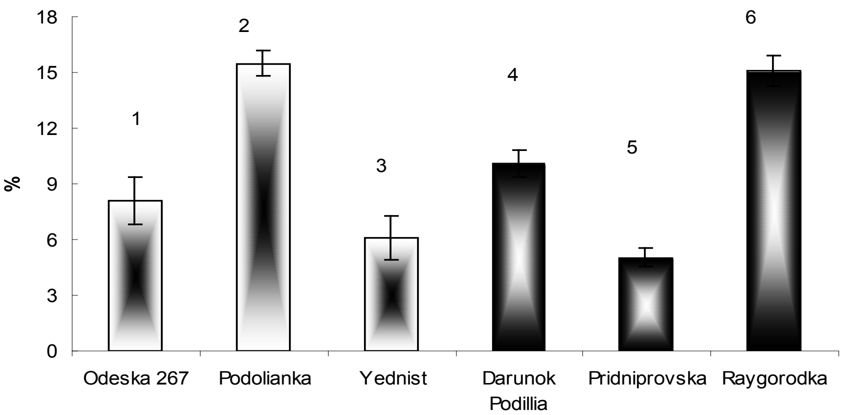
Table 5. Content and amount of non-structural carbohydrates in main stem of winter wheat varieties with different time of breeding at anthesis and full ripeness and the difference in their amount in these phases.

Variety	Content of non-structural carbohydrates, %		Amount of non-structural carbohydrates, mg/stem		Difference in amount at anthesis and full ripeness mg/stem
	Phase				
	anthesis	full	anthesi	full	

		ripeness	s	ripeness	
Odeska 267	22.1 ± 0.1	4.4 ± 0.1	211 ± 12	32 ± 2	179 ± 12
Podolianka	23.5 ± 0.3*	4.0 ± 0.3	236 ± 5*	30 ± 1	207 ± 5*
Yednist	18.2 ± 1.1*	5.8 ± 0.2*	147 ± 6*	39 ± 1	108 ± 6*
Darunok Podillia	21.0 ± 0.7*	4.1 ± 0.2	208 ± 6	32 ± 2	176 ± 6
Pridniprovska	19.5 ± 0.3*	6.5 ± 0.2*	165 ± 5*	43 ± 1*	122 ± 5*
Raygorodka	23.0 ± 0.1*	3.7 ± 0.1*	252 ± 8*	30 ± 1	222 ± 8*

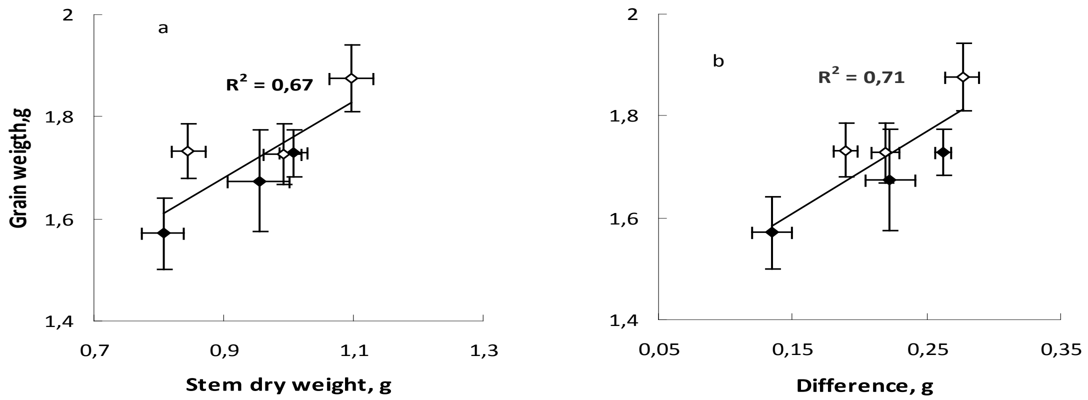
Larger dry matter weight of stem and higher non-structural carbohydrates content led to a higher amont of non-structural carbohydrates varieties Podolianka and Raygorodka at anthesis (236 and 252 mg/stem) and the highest difference in their amount at anthesis and full ripeness (207 and 222 mg/stem) (Table 5). This indicates that these two varieties had a larger pool of assimilates witch can be used for grain filling than other varieties. Indeed, calculations have shown that in the two most productive varieties the relative contribution of nonstructural carbohydrates to grain weight was the highest -about 15% (Figure 1). In modern varieties, Darunok Podillia and Pridniprovska, respectively, it was 5% and 10%, in the earlier breeding varieties of Yednist and Odeska 267 - 6 and 8%.

The analysis of the relationship between grain yield and stem deposited ability parameters of the main shoots showed that the grain weight was determined by stem dry matter weight of the main shoots weight at anthesis (r=0.82 ± 0.29) and by the difference of dry matter weight at anthesis and full ripeness (r=0.84 ± 0.27) (Figure 2). The correlation with non-structural carbohydrates content in main stem at anthesis, as well as the difference of their amount at anthesis and full maturity, was high, but due to the small sample size with significant errors of correlation coefficient (Table 6). The correlation of some indicators of deposed ability of main shoots stem with the yield were also high but not significant at 5% level significance, which is also related to the sample small size.



Note: 1-3 -modern varieties, 4-6 -old ones.

Figure 1. Relative contribution of non-structural carbohydrates to the spike yield, % to the grain weight.



Note: light sign are modern varieties, dark -old ones.

Figure 2. Relationship between dry matter weight of the main shoots stem at anthesis (a) and the difference of dry matter weight at anthesis and full ripeness (b).

Thus, high productivity of varieties Podolianka and Raygorodka was due to the formation of a larger pool of assimilates in the main shoots stem was established. Although there are drought resistant genotypes that do not have high yield potential, there is evidence that under stress conditions high-yielding varieties were more productive. In particular, it is shown that there is a close correlation between the yield of some wheat varieties with different yield potential under arid conditions, as well as under irrigation conditions (Hawkesford at al., 2013).

Table 6. The correlation coefficients between the grain productivity of main shoots spike and the yield with the parameters of main shoots stem deposited ability.

Parameters of deposited ability	Anthesis	Full ripeness	Difference at anthesis and full ripeness
	The correlation coefficients with the grain productivity of main shoots spike		
Stem dry matter weight	0.82 ± 0.29*	0.74 ± 0.33	0.84 ± 0.27*
Content of non-structural carbohydrates	0.68 ± 0.37	0.53 ± 0.42	-
Amount of non-structural carbohydrates	0.77 ± 0.32	0.44 ± 0.45	0.74 ± 0.33
	The correlation coefficients with the yield		
Stem dry matter weight	0.75 ± 0.33	0.68 ± 0.37	0.76 ± 0.33
Content of non-structural carbohydrates	0.67 ± 0.37	0.55 ± 0.42	-
Amount of non-structural carbohydrates	0.75 ± 0.33	0.49 ± 0.44	0.73 ± 0.34
Fisher’s criterion (the number of degrees of freedom=4) at p <0.05=2.78			

*Note: * -correlation is significant at p≤0.05.*

Thus, the features of varieties that retain high grain productivity in drought conditions are the high stem dry matter weight at anthesis, as well as their difference at anthesis and full ripeness. The grain filling in them under such conditions is carried out both by the account of non-structural carbohydrates and other substances, in particular, nitrogen-containing compounds, which are also capable of hydrolysis and remobilization in grains.

Conclusion

It was revealed that under conditions of drought during the reproductive period of development of winter wheat, the yield of varieties Raygorodka and Podolyanka was higher by 5-10% than the others. These varieties also had the higher stem dry matter weight at anthesis, the greater difference between its dry matter weight at anthesis and at full maturity, as well as the greater relative contribution of non-structural carbohydrates, accumulated by the stem during this period in the grain it was found. A close correlation between the grain and stem dry matter weight of the main shoots at anthesis, as well as difference between its dry matter weight at anthesis and at full maturity is established. High yield of winter wheat in drought conditions is associated with a high deposited ability of the stem during the vegetative period and a greater re-mobilization of assimilates accumulated during the reproductive period it is shown.

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