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Features of the photosynthetic activity of millet (*Panicum miliaceum* L.) in drought conditions.

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ABSTRACT

In the Pre-Kama zone of the Republic of Tatarstan, the main limiting factor of the yield of most crops is the drought. One of the ways of solving this problem is the selection of early ripening varieties, able to form seed harvest before the onset of adverse conditions. This paper presents a comparative characteristics of samples of millet (*Panicum miliaceum* L.) of mid-early and mid-season groups in terms of photosynthetic activity. We revealed the significant differences in area and dry biomass of leaves, photosynthetic potential of the samples of different maturity groups. Significantly lower values of some indicators of photosynthetic activity of mid-season group are due to drought conditions, coinciding with the functioning of assimilation surface. In dry weather conditions, the productivity of the main shoot is highly affected, directly and indirectly, by economic coefficient of the main panicle, the photosynthetic potential of leaves of the plant in general and the photosynthetic potential of the leaves of the lower and middle tiers.

Keywords: millet, maturity group, leaf area, photosynthetic potential, drought.

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INTRODUCTION

Photosynthesis in plants, as the primary source of organic matter, makes the basis of the production process. The photosynthetic activity of plants, ultimately determining the size and quality of the harvest, is a complex phenomenon that involves a number of the following essential components: the size of the photosynthetic apparatus, or leaf area, index of photosynthetic potential, the coefficient of economic productivity of photosynthesis, etc.

One of the most important indicators of photosynthetic activity of plants is the area of the leaf surface: its rapid growth to optimum size and a long active state contributes to a better use of solar radiation and increase productivity [1]. Leaf surface not only determines the amount of biological and economic yield, but also the course of its formation. One of the ways to optimize the photosynthetic activity of crops is the choice of varieties of a particular group of maturity for specific environmental conditions of cultivation [2, 3].

K.M. Kuzmina, V.A. Kumakov [2] noted that the late-season varieties are potentially more productive than early-season ones. Biologically this is due to their longer assimilation activity and the ability to form a greater number of leaves, secondary roots and spikelets. However, the listed potential capabilities can be realized only under favorable conditions during the entire growing period.

If we analyze the relation between the duration of the growing season and yield in specific environmental conditions, we can see no greater yield of late-season varieties. For example, in the Pre-Kama zone of the Republic of Tatarstan, the mid-season millet samples do not surpass mid-early varieties in grain yield, and are significantly behind in this indicator [4]. Real yield, according to N.P. Malchikoa [5], is determined not so much by vegetation conditions (precipitation rhythm and temperature), but their compliance with the dynamics of the most critical periods of formation of the elements of productivity.

A.V. Soloviov [6] found that the millet reaches its maximum leaf area by the phase of paniculation and "works" for the benefit of harvest on average for 23 days.

We believe that one of the main factors limiting the potential of mid-season millet samples in Pre-Kama zone of RT is a coincidence of a “critical” period (time of functioning of the assimilation leaf surface) of the samples of this group of maturity with drier weather conditions. The study of leaf area in samples of mid-early and mid-season groups in the interphase period: “full paniculation” - “full paniculation + 20 days”, provides insight into the essence of this process.

RESEARCH METHODS

Experimental studies were conducted in 2013 and 2014 on a group of varieties of millet seed selected in TatSRIA. Total 7 samples of mid-early and 10 samples of mid-season groups of millet seed (*Panicum miliaceum* L.) were studied. Crops were located on the fields of TatSRIA (Laishevsky district of RT, Russia).

In 2013, the process of grain filling proceeded under favorable hydrothermal conditions: the amount of precipitation was 42 mm, hydrothermal coefficient (HTC), [7] was equal to 0.98. In 2014, the process of grain filling proceeded under moderate dry weather conditions: the amount of precipitation was 25 mm, HTC = 0.65. The leaf area and dry leaf biomass was twice determined in 20 plants: in the phase of “full paniculation” and 20 days after the first determination.

The area of millet leaves with linear laminas was determined by formula: $S = 0.666 \times l \times b$, where l – length of the lamina, b – base width of the lamina.

For millet samples, we determined the photosynthetic potential of leaves in the interphase period of “full paniculation” - “full paniculation + 20 days” [8], the coefficient of economic productivity of photosynthesis ($C_{ec.}$), a daily decline in dry biomass of leaves, and a specific grain productivity (grain load per unit of leaf area) [9]. All indicators of photosynthetic activity were calculated for the main shoot.

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Weather data were provided by meteorological station of TatSRIA located in the village of Bolshie Kabany (Laishevsky district of RT, Russia). Data processing was performed with the use of AGROS - a software package of statistical and biometrics and genetic analyzes in plant growing and selection [10].

RESULTS AND DISCUSSIONS

In 2013, in the phase of "full paniculation", we revealed no significant differences between the mid-early and mid-season samples in leaf area (170.8 and 163.6 cm^2) and dry leaf biomass (1.03 and 0.97 g). However, after 20 days, the mid-season group showed significantly lower values of leaf area and dry leaf biomass: 67.81 cm^2 and 0.69 g, respectively (Table 1). If we consider the entire interphase period of "full paniculation" - "full paniculation + 20 days", we can see that its development was favorable for both groups of maturity, based on the amount of precipitation (56 and 54 mm) and the HTC values (1.45 and 1.39) (Table 2). However, if we break the interphase period into two decades, then the HTC value for the mid-season group in the second decade of the interphase period from August 1 to August 10 is 0. Thus, the extremely dry conditions have accelerated aging and dying-off of leaves in the mid-season plants. Photosynthetic potential of leaves in mid-season samples was "cut down" and amounted to 23.14 dm^2/day, which is significantly lower than in mid-early samples. This has affected the productivity of the developing panicles. The studies by Nour-Mohammadi et al. also showed decrease in the productivity of millet panicles under the influence of drought during the period of paniculation [11]. Majidi et al. [12] found that drought during paniculation causes failure of flowers and reduces size of millet grain.

Table 1. Productivity and indicators of photosynthetic activity of the main shoot, main panicle in the mid-early and mid-season samples.

Indicator	2013			2014		
	maturity group		$LSD_{0.05}$	maturity group		$LSD_{0.05}$
	Mid-early	Mid-season		Mid-early	Mid-season	
S_1, cm^2	170.77	163.61	–	152.49	119.65*	18.09
S_2, cm^2	122.12	67.81*	32.57	87.86	18.12*	27.86
S_1/S_2, %	100 /71.2	100 / 39.9		100 / 57.1	100 / 15.6	
PPl, dm^2/day	29.29	23.14*	5.59	24.04	13.78*	3.73
B_1, g	1.03	0.97	–	0.97	0.83*	0.08
B_2, g	0.80	0.69*	0.10	0.75	0.54*	0.16
B_1/B_2, %	100 / 76.9	100 / 70.4		100 / 77.1	100 / 67.1	
DBDD, g/day	11.8×10^{-3}	14.4×10^{-3}*	1.25×10^{-3}	11.2×10^{-3}	14.6×10^{-3}*	1.22×10^{-3}
SGP, g/dm^2	2.25	2.27	–	1.80*	2.08	0.18
Grain weight, g	3.84	3.72	–	2.75	2.49*	0.21
$C_{ec.}$ of main shoot	45.1	44.8	–	45.1	42.2*	2.68
$C_{ec.}$ of main panicle	82.1	81.7	–	79.0	76.7*	1.55

Note: hereinafter S_1 and B_1 - area and dry biomass of leaves in the phase of "full paniculation"; S_2 and B_2 - area and dry biomass of leaves in the phase of "full paniculation + 20 days"; PPl - photosynthetic potential of leaves in the interphase period of "full paniculation" - "full paniculation + 20 days"; DBDD - daily decline of dry biomass, SGP - specific grain productivity; the significantly lower values are marked with "*".

Table 2. Hydrothermal conditions and calendar dates of interphase period of "full paniculation" – "full paniculation + 20 days" in the millet samples of different groups of maturity.

Hydrothermal conditions and calendar dates of interphase period	2013				2014	
	mid-early		mid-season		mid-early	mid-season
Interphase period	July 15 – August 3		July 22 – August 10		July 16 – August 4	July 23 – August 11
Mean daily air t, ºC	19.3		19.35		18.7	20.0
Amount of precipitation, mm	56		54		32	24
HTC	1.45		1.39		0.78	0.54
Interphase period (10 days + 10 days)	July 15 - August	July 25 - August	July 22 - August	July 01 - August		

	24	03	31	10		
Mean daily air t, ºC	19.6	19.0	18.1	20.6		
Amount of precipitation, mm	4	52	54	0		
HTC	0.2	2.74	2.98	0		

According to our data, the photosynthetic potential of leaves increases in proportion to the leaf area and reaches its maximum in the interphase period of "full paniculation" – "grain filling". It was found that the growing millet productivity is primarily due to an increase in the proportion of photosynthetic potential falling on this interphase period [13]. The studies conducted on buckwheat (*Fagopyrum esculentum* Moench) also show that the maximum leaf area and the photosynthetic potential in the final stages of generative period correlate positively and significantly with seed productivity of plants and the variety yield [14].

As a result, in 2013, there was observed an equality of mid-early and mid-season samples in grain weight, $C_{ec.}$ and specific grain productivity of the main shoot, as well as the $C_{ec.}$ of the main panicle.

In 2014, in drier weather conditions of the studied interphase period (the amount of precipitation - 24 mm, HTC = 0.54) a group of mid-season samples was characterized by significantly higher values of the daily decline of dry biomass and specific grain productivity. Samples of this group of maturity had low values of leaf area and leaf dry biomass at the beginning and the end of the studied interphase period and the photosynthetic potential of the leaves, which resulted in the low value of productivity, main shoot and $C_{ec.}$ of main panicle.

G.V. Udovenko and E.A. Goncharov [15] believe that the effective method of reducing losses of crop as a result of stress is the selection of varieties, which onset of the critical periods of productivity formation of efficiency does not coincide with the time of the most acute stress in this region.

In the Pre-Kama zone of RT, the mid-early millet samples (due to the earlier calendar time of paniculation) "fudge" on the effects of drought during ontogenesis, the most sensitive period to such conditions (time of functioning of the assimilation surface of the leaves). While the time of functioning of the leaf apparatus in mid-season millet varieties coincides with dry weather conditions.

Dry conditions of the interphase period of "full paniculation" – "full paniculation + 20 days" not only accelerate the dying-off of leaves and "cut off" the photosynthetic potential of the mid-season samples, but also lead to changes in the share of the photosynthetic potential of the upper middle and lower leaves in terms of formation of the main shoot productivity (Table 3).

Table 3. Share of the photosynthetic potential of the upper middle and lower leaves in the total photosynthetic potential of leaves of the main shoot in the mid-early and mid-season groups, % and dm^2/day.

Group of maturity	Unit of measurement	2013			2014		
		PPl	PP of flag leaf	PP of middle and lower leaves	PPl	PP of flag leaf	PP of middle and lower leaves
mid-early	%	100	17.9	82.1	100	27.4	72.6
	dm^2/day	29.28	5.24	24.04	24.04	6.05	17.99
mid-season	%	100	28.3	71.7	100	29.3	70.7
	dm^2/day	23.14	5.94	17.2	13.78	3.95	9.83

In 2013, the mid-season samples in dry conditions of the studied interphase period had the share of the photosynthetic potential of the flag leaf equal to 28.3%, and the share of the photosynthetic capacity of middle and lower leaves – 71.7%. The same indicators of the mid-early samples under favorable conditions were 17.9 and 82.1%, respectively. The same situation was also observed in 2014.

N.P. Malchikov [16] foun from the selection assessment of signs of photosynthetic activity in millet seeds that, in dry conditions, the photosynthetic potential of middle and lower leaves has the most direct effect on the productivity of the main shoot. It was also shown that the direct and indirect effects of the photosynthetic capacity of the upper leaves differ little from zero, which indicates the absence of any of its significant influence on the formation of productivity of the main shoot.

For more detailed study of the influence of photosynthetic indicators on productivity of the main shoot of the millet selected in Tatar SRIA in dry conditions of the Pre-Kama zone of RT, we also applied the method of analysis of path coefficients that allows isolating the direct effect of one photosynthetic indicator and the indirect effects of others. Results of the analysis of the path coefficient are shown in Table 4.

Data in Table 4 indicate:

1) low direct contribution (-0.069) of $C_{ec.}$ of main shoot in the productivity of the main shoot. A significant positive correlation (r = 0.60*) of $C_{ec.}$ of main shoot with the efficiency is to a greater extent due to high indirect effects of $C_{ec.}$ of main panicle (0.580) and the photosynthetic potential of the leaves (0.701);
2) great direct contribution (0.774) of $C_{ec.}$ of main panicle in the productivity of the main shoot, which resulted in a significant positive correlation (r = 0.81*) between $C_{ec.}$ of main panicle and the productivity of the main shoot;

Table 4. Direct and indirect effects of photosynthetic indicators on the productivity of the main shoot in 2014.

Indicator	$C_{ec.}$ of main shoot	$C_{ec.}$ of main panicle	PPl	PP of flag leaf	PP of lower and middle leaves	r
$C_{ec.}$ of main shoot	**-0.069**	0.580	0.701	-0.103	-0.508	0.60*
$C_{ec.}$ of main panicle	-0.052	**0.774**	0.506	-0.095	-0.323	0.81*
PPl	-0.025	0.201	**1.948**	-0.203	-1.541	0.38
PP of flag leaf	-0.032	0.333	1.793	**-0.220**	-1.372	0.50*
PP of lower and middle leaves	-0.023	0.162	1.948	-0.196	**-1.541**	0.35
Po = 0.569						

Note: the path coefficients characterizing the direct effects are in bold; r - correlation coefficient of the ratio of the productivity of the main shoot to the photosynthetic indicators; the significant correlation coefficients are marked with "*".

3) great direct contribution (1.948) of photosynthetic potential of leaves in the productivity of the main shoot;
4) low direct contribution (-0.220) of photosynthetic potential of the flag leaf in the productivity of the main shoot. A significant positive (r = 0.50*) correlation between the photosynthetic potential of the flag leaf and the productivity is due to high positive indirect contribution (1.793) of the photosynthetic potential of the leaves and a high negative indirect contribution (-1.372) of the photosynthetic capacity of the middle and lower leaves;
5) great direct contribution (-1.541) of photosynthetic potential of the middle and lower leaves in the productivity of the main shoot.

Thus, our studies conducted in Pre-Kama zone of RT have confirmed the previously made findings by N.P. Malchikov [16].

SUMMARY

1. Coincidence of drought with the interphase period of "full paniculation" – "full paniculation + 20 days" results in decrease in the area, biomass, photosynthetic potential of the leaves and the seed production of the mid-season millet samples. The mid-early samples exceed significantly the mid-season samples in the studied photosynthetic indicators and productivity of the plants.
2. In the phase of "paniculation" in droughty conditions, there was observed an increase in the share of the photosynthetic potential of the flag leaf and decrease in the share of the photosynthetic potential of middle and lower leaves in the total photosynthetic potential of the main shoot leaves.

3. In dry weather conditions of Pre-Kama zone of RT, the productivity of the main shoot is highly affected, directly and indirectly, by economic coefficient of the main panicle, the photosynthetic potential of leaves of the plant in general and the photosynthetic potential of the leaves of the lower and middle tiers.

CONCLUSION

Our studies confirm that one of the main factors limiting the potential of mid-season millet samples in Pre-Kama zone of RT is a coincidence of the time of functioning of the assimilation leaf surface with dry weather conditions. The mid-early varieties provide higher grain yield due to their ability to “fudge” on drought.

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