Effect of moisture on photosynthesis and transpiration of buckwheat leaves

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Abstract. Currently, the issue of developing adaptive varieties of crops based on evolutionary principles is becoming urgent. The need to develop adaptive varieties for Russia is determined by the contrast of its natural and climatic conditions, global climate changes, and the increasing unpredictability of the weather. This task is highly relevant to the valuable food crop buckwheat, the yields of which are still low due to insufficient resistance of modern varieties to extreme environmental factors. Vegetation experiments to study the genotypic reaction of light and dark phases of photosynthesis of leaves on changes in soil moisture availability were carried out. During the period of buckwheat breeding from local samples to modern varieties the plants showed a significant trend in increasing the activity of photosynthesis and transpiration of plant leaves with a certain decrease in their resistance to moisture limitation. It was established that a decrease of soil moisture content from 70 to 30% of total moisture capacity caused, in modern cultivars, a mean decrease of fluorescence quantum yield by 52.5%, of electron-transport chain activity by 53.7%, of photosynthesis intensity by 66.5%, of transpiration intensity by 82.1%, whereas in local cultivars it decreased by 40.0%, 52.1%, 51.0%, and 76.1%, respectively.

1 Introduction

Recently, the need to create adaptive varieties based on evolutionary principles is increasing [1, 2, 3]. The relevance of breeding adaptive varieties for agricultural production is determined by both the contrasting natural and climatic conditions of Russia, and global climate changes, as well as the increasing unpredictability of the weather [4, 5, 6].

This task is also quite significant for buckwheat crop, the yield of which in Russia is still low (0.75 t/ha on average), primarily due to the insufficient resistance of modern varieties to extreme weather conditions of vegetation [7, 8]. Breeders plan to further increase the crop yield by reconstructing its adaptive genome [2], which requires scientific research on an interdisciplinary basis, in particular, with the active involvement of plant physiologists.

Taking into account the above-mentioned, we carried out vegetation experiments to study the reaction of photosynthesis and transpiration of leaves in buckwheat varieties of different breeding periods to changing environmental conditions. The present work presents

experimental data on the effect of soil moisture on photosynthetic and transpiration activity of leaves of local samples, old and modern buckwheat varieties.

The aim of this study is to identify the effect of selection on the adaptive properties of photosynthesis and transpiration of leaves of buckwheat plants (Fagopyrum esculentum Moench).

2 Materials and methods

The studies were conducted within the framework of the thematic plan of the Centre of collective usage of Orel State Agrarian University "Genetic resources of plants and their use" under the joint program with the breeders of Legumes and Groat Crops.

The objects of the main studies were 6 crop varieties of different breeding periods, which were conditionally divided into 3 groups: local populations from Orel Region (K-406 and K-1709); old varieties - breeding of 1930-1960s (Bogatyr and Shatilovskaya 5) and modern varieties - breeding of 1990s (Dozhdik and Dikul).

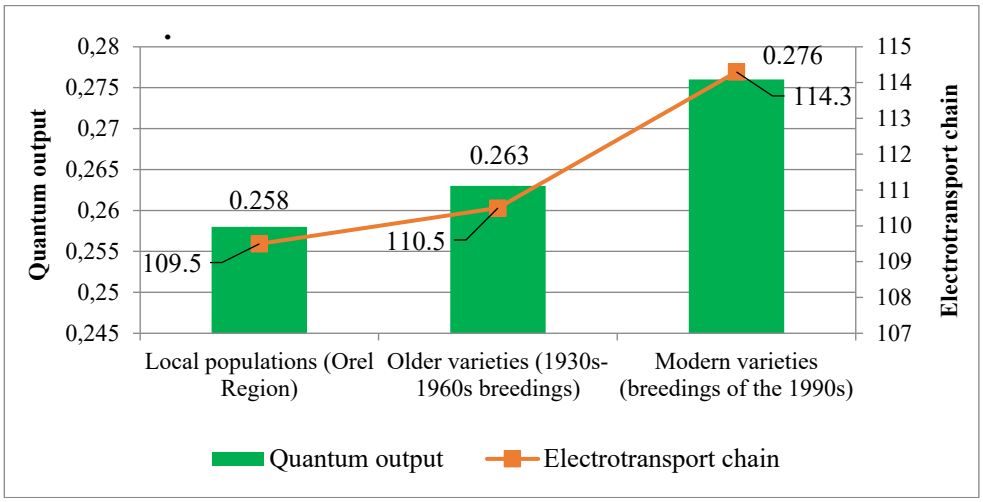
The experiments were carried out under the conditions of vegetative experiment. Plants of experimental varieties were grown in a breeding greenhouse by soil culture method using polymeric vessels with a capacity of 5 kg of dry soil. The effect of moistening conditions was studied at soil moisture content of 30 and 70% of full moisture capacity.

Chlorophyll fluorescence quantum yield, electrotransport chain activity, photosynthesis intensity, and transpiration were estimated by the original method of Heinz Walz GmbH (Germany) using a portable gas analyzer GFS-3000 FL. Water use efficiency was determined by calculating the ratio of the current values of photosynthesis intensity to the values of transpiration intensity.The measurements were performed on 5-7 plants typical of the genotype, whose leaves had no pest damage and disease lesions. Measurements were taken in real time on the 3rd (physiologically mature) leaf from the top of the main stem from 800 to 1100 hours, Moscow time. A light intensity of 1000 μmol photons Łm−2Łs−1 and air temperature 25 °C was maintained in the measuring chamber of the device.

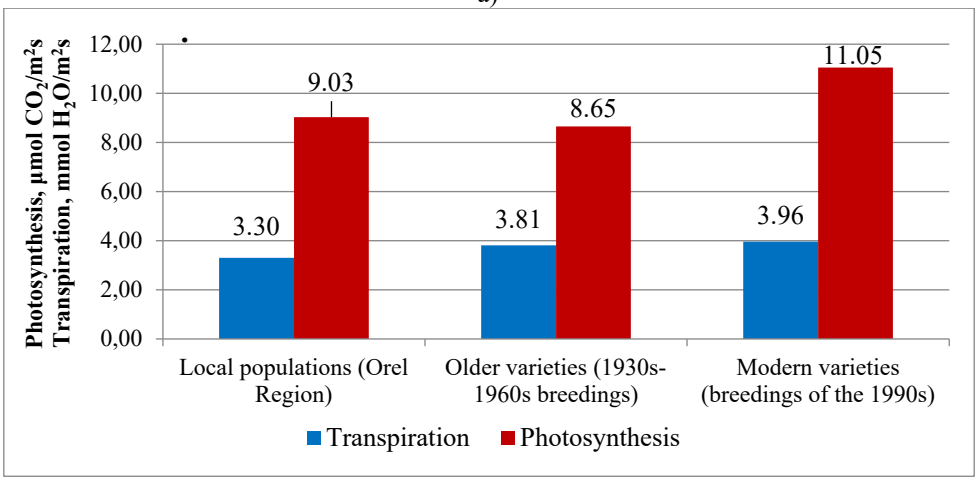
Statistical processing of the results (analysis of variance and correlation) was performed using Microsoft Excel 2013 and Statistica v. 10.0 (StatSoft, Inc., USA). Significance of differences was determined by Student's t-test at P = 0.95. Mean values (M) and standard deviations (±SD) were calculated.

3 Results and discussion

Previously, it was found that as a result of buckwheat breeding, a pronounced increase in physiological activity of leaves was observed in crop plants. According to the results of vegetation experiments carried out in 2022, during the selection period from local populations to modern cultivars the chlorophyll fluorescence quantum yield, electron transport chain activity, intensity of photosynthesis and transpiration of leaves increased in buckwheat plants in a phase "flowering + 10 days" on average by 6.5 %, 4.2 %, 22.4 %, and 20 %, respectively (Figure 1).



a)



b)

Fig. 1. Activity of light responses (a), the intensity of photosynthesis and transpiration (b) of leaves in buckwheat varieties of different breeding periods in the phase "flowering+10 days", according to the average data of the vegetative experiment in 2022.

However, under extreme weather conditions, the advantages of modern varieties in the physiological activity of plant leaves are leveled, since as a result of breeding in buckwheat plants there is a pronounced tendency to reduce the stability not only of productivity, but also of photosynthetic process [9]. Under conditions of growing experiment, with a decrease in soil moisture content from 70 to 30% of full moisture capacity, the values of quantum yield and electron transport circuit decreased in modern cultivars by an average of 52.5% and 53.7%, respectively. Whereas in local varieties the decrease in values of these indicators was 40.0% and 52.1%, respectively, compared with the control variant (Table 1).

Especially significant is the negative effect of extreme conditions of soil moisture on the activity of assimilation of CO2 molecules and transpiration of plant leaves. It was shown that at soil moisture content of 30% of full moisture capacity the intensity of leaf photosynthesis in buckwheat plants was 58.1% on average and the intensity of transpiration was 80.0% lower compared with the optimal soil moisture content (70% of full moisture capacity).

Table 1. Activity of light reactions of leaf photosynthesis in buckwheat varieties depending on soil moisture in the flowering phase, 2022.

Variety	Quantum output			Electrotransport chain		
	Flowering	Flowering+10 days		Flowering	Flowering+10 days	
	Control*	Control	Experience	Control	Control	Experience
Local populations (Orel Region)						
K –406	0.247	0.251	0.153	104.5	108.4	51.4
K–1709	0.260	0.265	0.157	109.8	110.6	54.6
Average	0.254	0.258	0.155	107.2	109.5	53.0
Older varieties (1930s-1960s breedings)						
Bogatyr	0.283	0.285	0.149	118.3	123.5	59.7
Shatilovskaya 5	0.188	0.241	0.134	81.2	97.4	54.6
Average	0.236	0.263	0.142	99.8	110.5	57.2
Modern varieties (breedings of the 1990s)						
Dikul	0.279	0.283	0.133	116.5	118.4	54.2
Dozhdik	0.255	0.268	0.129	107.8	110.2	51.5
Average	0.267	0.276	0.131	112.2	114.3	52.9
HCP05	0.012	0.016	0.013	4.4	4.2	4.3

*Control - 70% of full moisture capacity, experience - 30% of full moisture capacity.

Table 2. Intensity of photosynthesis and transpiration in buckwheat varieties depending on soil moisture during flowering phase, 2022.

Variety	Photosynthesis, μmol CO_2/m^2s			Transpiration, mmol H_2O/m^2s		
	Flowering	Flowering+10 days		Flowering	Flowering+10 days	
	Control*	Control	Experience	Control	Control	Experience
Local populations (Orel Region)						
K –406	7.23	8.24	4.17	2.36	3.16	0.71
K–1709	8.45	9.81	4.72	3.03	3.43	0.86
Average	7.84	9.03	4.45	2.70	3.30	0.79
Older varieties (1930s-1960s breedings)						
Bogatyr	7.89	8.25	4.55	3.14	3.77	0.79
Shatilovskaya 5	8.65	9.04	3.41	3.21	3.84	0.67
Average	8.27	8.65	3.98	3.18	3.81	0.73
Modern varieties (breedings of the 1990s)						
Dikul	9.87	10.88	3.64	3.25	3.91	0.73
Dozhdik	10.07	11.21	3.75	3.51	4.01	0.69
Average	9.97	11.05	3.70	3.38	3.96	0.71
HCP05	0.67	0.71	0.62	0.41	0.34	0.10

*Control - 70% of full moisture capacity, experience - 30% of full moisture capacity.

Moreover, under conditions of limited moisture in local samples the intensity of photosynthesis and transpiration of leaves decreased by 51.0% and 76.1 %, and in modern varieties Dikul and Dozhdik on average by 66.5% and 82.1% (Table 2).

That is, the conclusion that the photosynthetic system of plants in local buckwheat varieties is subjected to stress to a lesser extent than in modern varieties is confirmed.

It was found that one of the reasons for weak adaptation of modern varieties to stress is lower efficiency of evaporated water use for photosynthesis due to increased transpiration. Under the drought conditions of 2010, the values of water use efficiency of modern varieties of buckwheat were on average 12.2% lower and transpiration rate by 11.4% higher compared with the local cultivars (Figure 2).

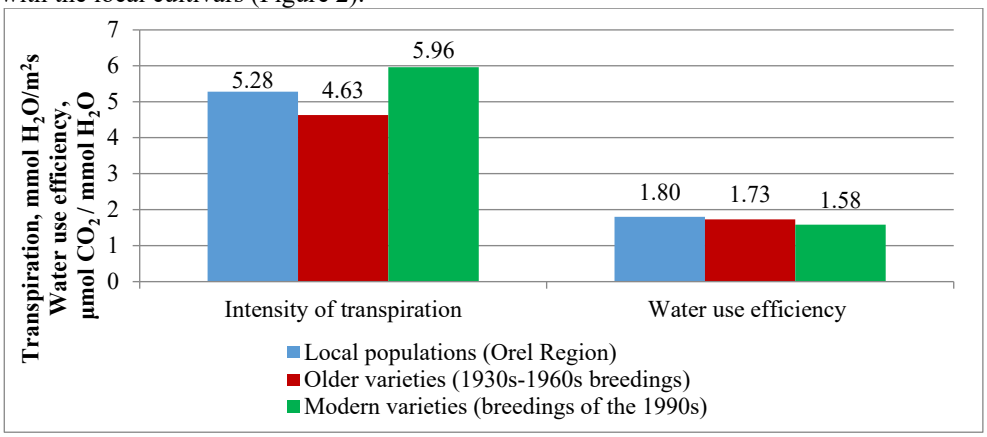


Fig. 2. Water use efficiency and transpiration rate of buckwheat varieties of different selection periods under drought conditions in 2010.

It is known that water use efficiency is related to photosynthetic rate and transpiration activity [10]. In our studies the correlation coefficient between water use efficiency and leaf photosynthetic rate was positive ($r = +0.69$, $p < 0.05$) and negative for transpiration rate ($r = -0.89$, $p < 0.05$). In modern cultivars high water use efficiency is mainly observed under favorable weather conditions of vegetation, primarily due to repeated dry and warm weather. During the period of crop selection from local populations to the best modern released varieties, the values of water use efficiency of plants have become higher ($P = 0.95$) on average by 20.5 %, photosynthesis intensity - by 29.0 %, transpiration - by 7.9 %, which significantly contributed to growth of seed productivity of plants.

4 Conclusion

It is confirmed that as a result of selection in buckwheat plants there is a marked increase in the physiological activity of leaves. According to the results of experiments, during the selection period from local populations to modern varieties, the quantum yield of chlorophyll fluorescence, electron transport chain activity, photosynthesis intensity and leaf transpiration increased in buckwheat plants during the phase "flowering + 10 days" on average by 6.5%, 4.2%, 22.4%, and 20%, respectively.

However, the stability of the photosynthetic system of plants weakened. Under conditions of limited moisture in modern varieties it is subjected to stress to a greater extent than in local samples. Decrease of soil humidity from 70 to 30% of total moisture capacity causes decrease of quantum yield of fluorescence in modern cultivars by 52.5% on average, of electron-transport chain activity by 53.7%, of photosynthesis intensity by 66.5%, of transpiration

intensity by 82.1%, while in local samples it decreased by 40.0%, 52.1%, 51.0%, and 76. %, respectively.

One of the reasons of poor adaptation of modern varieties to stress is lower efficiency of evaporated water use for photosynthesis due to increased transpiration. Leaf photosynthesis intensity has a positive effect on the efficiency of water use by plants (r = +0.69), while transpiration intensity has a negative effect (r = –0.89). Depending on the nature of the manifestation of these processes in ontogenesis and during the day buckwheat varieties can differ significantly in the efficiency of water use. As a result of selection the water use efficiency increased on average by 20,5 %, which was caused by an increase of photosynthetic activity by 29,0 % and transpiration by 7,9 %, which had a positive effect on the growth of crop yield, but only under favorable conditions of vegetation. Selection of forms with increased photosynthetic activity and moderate transpiration can be considered as one of the priority areas of crop breeding.

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