Donor-acceptor relations influence on the modern spring wheat varieties photosynthetic system activity

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Abstract. The article presents the field experiments' many years results on the leaves photosynthetic activity manifestation varietal aspects study in spring wheat plants. It was shown on 25 modern cultivars that the leaf photosynthesis intensity significantly depends on the donor-acceptor relationships in nature, which are determined by the plants' hereditary characteristics, the growth phase, location and vegetation conditions. The most active CO₂ molecules assimilation from the air is the plants flag leaf, on which the main fruit load falls. During the caryopsis formation period, in photosynthesis intensity terms, it exceeded the pre-flag leaf by an average of 1.5 times, and the lower one by 2.7 times. In special model field experiments, it was found that its removal from plants leads to an increase in the pre-flag leaf photosynthesis intensity by an average of 35.4%, and the third from the top by 28.0%. When the flag leaf remains alone, and the rest are removed, its CO₂ assimilation intensity increases only by 5.6%. It was concluded that the spring wheat genetic resources are characterized by a plant leaves photosynthesis intensity sufficiently wide polymorphism to effectively select forms with a photosynthesis high activity and purposefully use inbreeding. Work in this direction may well be successful since the leaves photosynthesis intensity in culture plants is high hereditary conditioning.

1. Introduction

Donor-acceptor relations play a leading role in the photosynthetic activity manifestation and the yield formation by crops varieties [1].

It was shown that all chlorophyll-containing plant organs have a photosynthetic activity to one degree or another [2-5]. Their activity efficiency is determined by a photosynthesis integration and cooperative relationships complex system with the plant organism all functions [1, 6]. During the crop formation, the main photosynthetic load in the whole plant system falls on the leaves: in beans, their contribution to the plant photosystem can reach 92 ... 94% [7], and in wheat - 82% [8].

It is believed that the chloroplast potential is large enough to provide a stable increase in photosynthetic activity at the phenotypic level even at a CO₂ natural concentration, and the varieties' creation with the high HI can lead to the photosynthesis intensification at the genetic level [6]. This is confirmed, in particular, by winter wheat, in whose plants and increase in HI as a selection result is accompanied by a significant increase in the leaf photosynthesis activity [10-12]. In this culture' modern varieties, the photosynthesis intensity per leaf area unit is 44% higher than that of those created in the
1950s. Moreover, for six phenological phases (during the period from entering the tube to grain milk ripeness), a close correlation was found between the yield value and the leaf photosynthesis intensity \( r = 0.61 \) and stomatal conductance \( r = 0.67 \) [13].

However, other crops have an increase in HI. in newly created varieties, although it serves as the main mechanism for increasing their productivity, it is not always associated with the photosynthetic apparatus activation. For example, in spring wheat, the leaf photosynthesis net productivity value during the 45 years of its selection (1924-1970) in the Upper Volga region did not change significantly. This trait turned out to be conservative, and the increase in yield is achieved mainly due to an increase in the photosynthetic potential and its functioning duration in development in certain periods [9]. Considering that at present, in spring wheat many modern varieties, the dry matter proportion used for seed formation has already exceeded 50% [14], and the plants' morphotype and the development interphase periods duration are optimized to a certain extent, then further growth in yield can be provided only by enhancing the organic matter biosynthesis, which is 95% created by photosynthesis. In this connection, it is very important for crop breeding to identify the increasing photosynthesis activity and efficiency possibilities in the plants' production process.

The study purpose is to establish the role of the donor-acceptor relations in increasing the plants photosynthetic activity in spring plants' modern varieties and changing them priority ways inbreeding.

2. Methodology
The studies were carried out during 2017-2020 on the Oryol State Agrarian University Plant Genetic Resources and Their Use Center for Collective Use basis under a joint program with the Shatilovo Agricultural and Chemical Plant of the Federal Research Center of Legumes and Cereals and with the Russian Federation Ministry of Agriculture support.

The study object was spring wheat 25 modern varieties from Russia leading breeding centres. The culture cultivars were tested at the Shatilovo Agricultural and Chemical Plant in the field on plots with an area of 25m² placed randomly in 4 replicates.

Model experiments to study the donor-acceptor relations' effect on the plant leaves photoactivity was carried out on 4 crop varieties (Arseya, Voronezhskaya 20, Liza, Triada), which differed in the yield size and the harvesting index. In the heading phase, individual leaves and ears were artificially removed from 30 plants of each variety in a certain sequence. After 3 days, using a portable gas analyser GFS-3000 FL of the German company WALZ on experimental plants in real-time, the photosynthesis activity indicators were recorded. Intact plants growing in the plot middle, in which the leaves were not damaged by pests and diseases, served as control. Measurements were carried out in the growth main phases (tillering, stemming, heading, milky ripeness, milky-wax ripeness and the milky-wax ripeness end) during the day (from 7:00 am to 7:00 pm Moscow time) on leaves 5-7 typical plants for the variety, located in different tiers (flag, pre-flag and downstream). In the measuring chamber attached to the device leaves, the light intensity was maintained at 1000 μmol/m²s., and the CO₂ concentration was 0.033. At the same time, natural lighting, air temperature and humidity were taken into account, as well as their average annual values in the region.

The experimental data mathematical processing was carried out using modern computer programs.

3. Research results
It was shown that the leaf photosynthesis intensity in spring wheat' modern varieties has a high hereditary condition and weak phenotypic dependence. The trait genotypic variability range was: in 2017 - 9.65 ... 16.35; in 2018 - 9.55 ... 21.42; in 2019 - 8.73 ... 17.15; in 2020 - 12.06 ... 15.24 μmol CO₂/m²c. Depending on the growing season weather conditions, its value changed to a much lesser extent - from 12.39 to 13.39 μmol CO₂/m²c.

The studied varieties most (about 65%) had CO₂ assimilation relatively high rate by plant leaves - on average 15.15 μmol CO₂/m²c. In others, its value was 15.8% less and averaged 12.75 μmol CO₂/m²c. The revealed genotypic differences in the leaves photosynthetic activity were manifested throughout almost the entire growing season, but the most significant ones were recorded in the tillering phase,
stemming and the caryopses filling period (milky - milky-wax ripeness). The cultivars with a photosynthesis high intensity in the tillering and tubing phases were superior to the cultivars with a CO₂ low assimilating capacity by an average of 28%, and in the milk ripeness phase - by 31%. No significant differences were found in the heading phase (table 1).

Table 1. Leaves photosynthesis Intensity (PHI) in spring wheat experimental varieties’ ontogenesis with PHI different levels.

| Varieties group | Growth phase          | Tillering | Entering the tube phase | Heading | Flowering | Milk ripeness | Milky-wax ripeness |
|-----------------|-----------------------|-----------|-------------------------|---------|-----------|--------------|-------------------|
| With increased PHI |                       | 16.20     | 21.37                   | 16.86   | 15.53     | 12.48        | 8.51              |
| With reduced PHI |                       | 11.35     | 18.90                   | 16.28   | 11.78     | 11.35        | 6.84              |

A significant relationship between the yield and the photosynthesis intensity was mainly manifested during the filling’ the caryopses period, which was probably due to the increasing demand for photoassimilates. The correlation coefficient between the variety yield and the photosynthesis intensity was positive and averaged 0.62 at this time (at P05). Varieties with increased photosynthetic activity, as a rule, were also characterized by higher grain yields (figure 1).

This suggests that, due to selection and in the spring wheat plants photosynthetic system, significant changes begin to occur. Discovered 50 years ago by V.A. Kumakov [8, 9] leaves photosynthetic activity conservatism, apparently, is overcome, and now it begins to play an increasingly noticeable role in achieving high crop yields, although purposeful selection work in this direction has not been carried out.

At the same time, the photosynthesis intensity correlation coefficient with the harvesting index was insignificant and had a predominantly negative value. During the research years, its value between these characters varied from -0.40 to +0.38 in the phase of entering the tube, and from -0.10 to -0.39 during the filling’ the caryopses period (figure 2).

This means that the ongoing changes in the modern crop varieties' plants photosynthetic systems, in this case, are little caused by an increase in the harvesting index, which has already reached its maximum value [14]. It is known that the photosynthesis activity can significantly depend not only on the demand for assimilates but also on the leaves stomatal conductance [15] and the key enzyme RuBisc [16], which requires this issue additional study in the culture.
Figure 2. Harvesting index (HI) and the spring wheat varieties photosynthesis (PHI) intensity during the study years.

It was found that in spring wheat' modern varieties, the growing season weather conditions regardless, CO₂ molecules are most actively assimilated from the air by the plants flag leaf. During the caryopses' formation, its photosynthesis intensity in 2017 was 1.6 times higher than the pre-flag leaf, and 2.8 times higher than that of the downstream leaf, 1.6 and 2.2 times in 2018, and in 2019 - 1.4 and 3.9 times, respectively, which indicates its leading role in the plants' photosynthetic system (figure 3).

Figure 3. Leaves photosynthesis (PHI) Intensity depending on their layered arrangement on the plant in spring wheat cultivars in the caryopses mass filling phase, on average for cultivars over the research years.

The photosynthesis primary reactions' activity changes similarly: its value in the culture plants lower leaves is on average 2.3 times lower than in the upper ones [3].

In special model field experiments, it was shown that the flag leaf artificial removal in plants leads to an increase in the pre flag leaf photosynthesis intensity by an average of 35.4%, and in the underlying (3rd from above)-by 28.0%. When the flag leaf remains alone, and the rest are removed, its CO₂ assimilation intensity increases only by 5.6%.
Figure 4. Spring wheat leaves photosynthesis (PHI) intensity with their removal' different options from plants, on average for varieties for 2020. Option 1 (control) - flag, pre-flag and 3rd leaf from the top; Option 2 - flag sheet (removed pre-flag and 3rd leaf from the top); Option 3 is a pre-flag sheet (removed the flag and 3rd leaf from the top); Option 4 - 3rd leaf from the top (removed flag and pre flag leaves); Option 5 - flag and pre-flag leaves (removed 3rd leaf from the top); Option 6 - flag and 3rd sheet on top (removed pre flag leaf); Option 7 - pre-7 and 3rd sheet on top (removed flag sheet); option 8 - flag, pre-flag and 3rd sheet from the top (removed ear).

This confirms the conclusion that in the plant whole system, the spring wheat flag leaf carries the main photosynthetic load during the grains formation and pouring [8]. In modern high-yielding crop varieties, its activity, is close to the maximum possible. Therefore, it is justified that the promising genotypes' selection is proposed to be carried out on the flag leaf, which plays an axial role in providing the ear photoassimilates grain [18].

Figure 5. The leaves' photosynthesis intensity (PhI) daily dynamics in spring wheat' modern varieties in the grains milk ripeness phase, average for varieties for 2020.
It should be taken into account that the plants’ photosynthetic process can be limited to both the leaves themselves photoactivity and the attracting centres’ activity because in the whole plant's system photosynthesis is not only the energy-plastic substrates and regulatory compounds main source for attracting centres, but also is itself subject to the latter significant influence through the hormonal inhibitor system [1, 19].

In experiments, with ear plants artificial removal, the leaves’ photosynthesis intensity in spring wheat’ varieties was reduced in comparison with control: the flag leaf - an average of 17.3%, pre flag - by 9.7% (see figure 4).

During the day, the plant leaves photosynthesis the highest intensity from 9 to 11 o'clock, when the cells' turgor remains high enough, photosynthetic active radiation reaches subsolcentiation values, and the air temperature is optimal (18-22°C) for active growth and development, which is important to consider when assessing the selection material (figure 5).

4. Conclusions
The spring wheat genetic resources are characterized by a plant leaves photosynthesis intensity wide enough polymorphism to effectively select forms with photosynthesis high activity and purposefully used in breeding, taking into account the growth phase, day time and the trait longline variability. Work in this direction may well be successful, as the leaves’ photosynthesis intensity in culture plants has high hereditary conditioning.

Interbreedings involving sources of high leaf photoactivity have highlighted lines that have significant advantages over parental forms in photosynthesis and seed productivity terms [20].

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