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Photosynthetic and symbiotic efficiency in shaping the yield of pea seed in the agro-ecological conditions of the southern forest-steppe of Western Siberia

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Abstract. The article presents data on the contribution of photosynthetic processes and symbiotic nitrogen fixation to the productivity of pea seeds. The interdependence of the processes of photosynthesis and nodule formation has been revealed, as well as the share of influence of factors on yield formation.

1. Introduction

The modern basis for effective agrarian nature management is not only obtaining high yields, but also using the biopotential of all components of agrocenosis. In this regard, the use of plant-microbial interactions, as well as the creation and cultivation of varieties of crops that maximize the use of sun energy for the formation of yields, are very promising areas today.

The purpose of the research was to study the intraspecific polymorphism of pea seed on the basis of yield, grain quality, symbiotic and photosynthetic efficiency in contrasting conditions of the southern forest-steppe of Western Siberia and the selection of new genetic sources of these characters.

2. Materials and methods

The studies were carried out on the fields of the laboratory for the selection of leguminous crops at the Omsk Agrarian Research Center in 2006–2008 and 2010–2012. The soil of the experimental plot is meadow chernozem with an arable horizon of 25–30 cm, humus content of 6.3–6.5%, the amount of absorbed bases is 26–48 mg eq. / 100 g, and pH – 6.5–6.7 (according to agrochemistry laboratories Omsk Agricultural Research Center). The years of research were contrasting in moisture and heat supply.

As the object of research, 12 variety samples of sowing peas were used: Omsky 9, Omsky 7, Zauralsky 1, Batrak, Talovets 55, Blagovest, Demos, Omsk incessant, L 35/03 (Bonus), L 34/01, L 36/03, L 37/03 (Omsky 18).

The experiments were laid on plots of 10 m², in quadruplicate. The precursor is soft spring wheat. The seeding rate is 1.2 million viable seeds per hectare. Sowing was carried out with the «SFFC» drill - 7.0, harvesting with the «Hege 125» combine in the phase of full ripeness. Agrotechnology - generally accepted for the zone of the southern forest-steppe of Western Siberia. Sampling was carried out



according to the main phases of plant development: full germination, budding, flowering, fruit formation.

3. Results and discussion

3.1. *The formation of a symbiotic apparatus in peas*

When studying the dynamics of nodule formation in pea plants for the period 2006–2008 significant differences were identified.

The formation of nodules in varieties and pea lines proceeded gradually. Beginning in the phase of 2–4 true leaves, it reached a maximum towards the flowering phase, and by the time of fruit formation this process was weakened. On average, the varieties for the years of study the maximum number of nodules - 26.2 pieces / plant was formed in the flowering phase, their weight was 187.3 mg / plant.

In 2008 all the studied pea genotypes in the analyzed developmental phases had an increase in the number of active nodules 2.0–2.8 times more than in 2006. The nodule weight was also significantly higher - 158.9 mg / plant, in 2006 it was 41.3 mg / plant. These differences are associated with both the hydrothermal conditions of the growing season and the amount of nitrate nitrogen in the soil. In 2006, at the same time, a high concentration of nitrate nitrogen in the soil (15.2 mg / kg in a layer of 0–40 cm before sowing) and unfavorable hydrothermal conditions prevented the formation of nodules; the symbiotic apparatus of plants was characterized by small, difficult to separate nodules. 2008 was characterized by an optimal amount of productive moisture (21.9 mm) and nutrients in the soil before sowing and a favorable combination of heat and moisture during the growing season.

Conducted research allowed to identify and varietal differences for the studied characteristics. On average, varieties of specimens with a baleen leaf type had an increased ability to nodule formation. Among the variety samples of the mustache morphotype, the highest number and mass of nodules were characterized by L 37/03 (Omsky 18) and the variety Batrak, and the advantages of these samples were noted during all studied phases of development. It stands out and grade Blagovest. Its peculiarity was the ability to intensively form nodules in the initial period of development, gradually increase their potential for flowering and retain a sufficiently large number of nodules in the fruit formation phase [1].

When studying the signs, the number of nodules and their mass in the dynamics of ontogenesis of pea plants for the period 2010–2012 found that their greatest value in most varieties is noted in the budding phase. The exception is the line L 37/03 (Omsky 18), in which the peak of formation falls on the flowering phase, when large nodules form on the plant. This is due to the longer interphase periods of the first half of the growing season and, as a consequence, the later growth of the vegetative mass.

You can also distinguish the variety Demos, which according to the results of unfavorable 2011, the maximum number of large nodules was noted in the flowering phase and the growth process of the symbiotic apparatus continued until the fruit formation phase, whereas in the rest of the variety samples, the nodule formation significantly decreased already by the flowering phase.

According to the results of 2010-2012 it was revealed that, on average, 28.26 pcs. are formed during the budding phase nodules on a plant with a mass of 0.22 g. The most favorable conditions for the formation of full-fledged nodules were the conditions of 2012.

Accounting for the number and mass of nitrogen-fixing nodules is necessary when characterizing the symbiotic apparatus of leguminous crops. Active symbiotic potential (ASP) - takes into account the mass of active nodules and the duration of their functioning. In the years favorable for nodulation (2008 and 2010), the highest value of this indicator was noted. On average, for all studied pea samples, the value of ASP as a whole during the growing season was $3789 \text{ kg} \times \text{d} / \text{ha}$ and was determined mainly by the mass of nitrogen-fixing nodules. The data of two-factor analysis of variance showed that growing conditions (72.4%) had a decisive influence on the formation of a symbiotic apparatus in peas.

3.2. *Features of the formation of the photosynthetic apparatus pea plants*

The intensity of growth of the above-ground plant mass is characterized by biometric indicators: height, mass of plants (without root), weight of green leaves with stipules, weight of reproductive organs. In

2010, the most favorable conditions for the formation of aboveground organs. The peak of the increase in the aerial mass was noted in the flowering phase. The largest elevated mass was characterized by variety samples Demos and L 37/03 (Omsky 18).

One of the most important physiological characteristics of a variety (morphotype) is the leaf area, which in the system of the assimilation apparatus makes the main contribution to the formation of the final harvest.

As a result of research, it has been established that an increase in the leaf area occurs gradually, the peak of this indicator is noted in the flowering phase. The conditions of 2011 were most favorable for the formation of the leaf surface of peas, the average for the variety samples, this figure was $282.63 \text{ cm}^2 / \text{plant}$. The maximum leaf surface area was formed by the variety samples Omsky 7 and L 37/03 (Omsky 18).

The photosynthetic potential of plants (PP) is closely related to the size of the leaf area and the duration of their work. The highest PP value was observed in the Omsky 7 variety and the L 37/03 line (Omsky 18), the latter being characterized by the stable operation of the assimilation apparatus and the prolonged preservation of the leaves.

Along with the photosynthetic potential, the net photosynthesis productivity is widely used in research practice. The research results showed that, on average, over the years of testing, the photosynthesis productivity for the studied variety samples as a whole during the growing season was $38.7 \text{ g} / \text{m}^2 \times \text{day}$. The highest photosynthesis productivity value was noted in 2012 - $50.10 \text{ g} / \text{m}^2 \times \text{day}$. The efficiency of the photosynthetic apparatus in the development phases of the studied variety samples was different.

The cultivars Omsky 9 and L 37/03 (Omsky 18) were characterized by the highest photosynthesis productivity value in the flowering phase, in Blagovest cultivar, the maximum photosynthesis productivity was noted in the budding phase, in Omsky 7 and Demos - to fruit formation.

According to the results of the research, the highest photosynthesis productivity value during the growing season was characterized by Omsky 9 varieties - 44.99, Demos - 39.57 and Blagovest - 38.88 $\text{g} / \text{m}^2 \times \text{day}$.

For a comparative assessment of the characteristics of the formation of seed productivity in varieties allocate harvest index (K_{hoz}), which is subject to the influence of agro-ecological factors.

As studies have shown, on average, over the years of study, K_{hoz} made 30.35%. The maximum values of this indicator were noted in the variety Omsky 7 - 46% (2010); lines L 37/03 (Omsk 18) - 35.54% (2011) and in the variety Demos - 34.11% (2012).

The share of influence of factors on the index of the harvest index is revealed. The conditions of the year (B) - 75.2% had the greatest effect on this indicator, first of all - the sum of effective temperatures in the period of emergence – flowering ($r = +0.81$), to a lesser extent - the amount of precipitation in this period ($r = +0.61$). The influence of the genotype (A) was insignificant - 6%, the share of the influence of the combination of factors (AB) was 18.9% [2].

3.3. Formation of productivity of sowing peas

A complex indicator of adaptability, the effectiveness of symbiotic nitrogen fixation and photosynthesis of leguminous crops is the productivity of plants.

For the period 2006–2008 high yields of all studied varieties and pea lines with a baleen leaf type were observed in the most favorable weather conditions of 2008, which amounted to an average of 3.72 tons / ha, exceeding by 0.96 and 0.77 tons / ha yield indicators 2006 and 2007 [6].

In contrasting hydrothermal conditions 2010–2012 productivity indicators were different. The maximum yield of pea grain - 3.17 tons / ha was recorded in 2010, the minimum - 1.89 tons / ha in 2012. Among the variety samples, the highest yield was obtained for the line L 37/03 (Omsky 18). It confirmed its adaptability by high productivity in adverse hydrothermal conditions of 2012, exceeding the yield of the standard variety Omsky 9 by 0.66 tons / ha [3].

It was established that the yield of genotypes was determined by the following elements of its structure: the length of the stem ($r = +0.77$), the number of productive nodes ($r = +0.76$), the number of seeds ($r = +0.55$), the mass of 1000 seeds ($r = +0.75$).

The results of two-factor analysis of variance showed that the conditions of the year (B) had the greatest impact on the formation of the yield of varieties of peas - 86.8%. The proportion of influence of the genotype (A) was 9.8%. The effect of the interaction of the two studied factors (AB) on the grain yield was weak - 3.4%.

3.4 Pea Grain Quality

The determining indicator of the value of a variety is not only its yield, but also its quality.

Analysis of experimental data for the period 2006–2008 showed that the protein content in pea grains changed over the years of experiments and averaged 23.2% over 3 years.

Conditions of 2008 were the most favorable for the process of nodulation and protein accumulation in pea seeds. Despite the high yield level, the average grade of protein was the highest for the years of research - 24.1%. The greatest potential (25.5% of protein) was shown by the variety Demos. The maximum increase to the standard was also noted for this variety in 2007 - 4.0%.

On average, over 3 years, a relatively high percentage of protein in grain ranging from 23.3 to 23.8% had the following variety samples: Blagovest, Batrak, L 37/03 (Omsky 18), Zauralsky 1. It should be noted that the line L 34/01, which exceeded the standard for the studied indicator in 2007 by 1.8% and only surpassed the grade Demos. The lowest protein content was observed in the Omsky 9 and Omsky 7 varieties - 22.3% and 22.4%, respectively [3].

For the period 2010–2012 it was established that the protein content in pea grains varied over the years and averaged by varietal samples 22.28%. Conditions of 2010 were most favorable for protein accumulation in pea grains. Demos was the most high-protein of the genotypes studied — 23.55%, L 37/03 (Omsky 18) — 22.42 [3].

The collection of protein per hectare is characteristic of any variety. On average, over the years of study, the collection of protein with the yield of pea grain was 651.5 kg / ha. The maximum protein harvest was noted in 2008 and 2010 - 886 and 865 kg / ha, respectively.

The breeding line L 37/03 (Omsky 18) - 757 kg / ha became the leader in collecting protein per hectare. In 2008 and 2010 from the studied line, the collection of protein was maximum for the entire study period - 1015 kg / ha.

3.5. Contribution of photosynthesis and symbiotic nitrogen fixation in the productivity of grain pea

To identify the relationship between productivity and indicators of nodulation and photosynthesis of pea plants for the period 2010–2012 correlation coefficients between these indicators were determined. In our experience, the nature of relationships was different over the years.

The largest number of positive relationships was observed in more favorable agro-ecological conditions of 2010 and 2012.

It was established that the formation of yield was significantly influenced by the area of the formed leaves ($r = +0.97$), the photosynthetic potential ($r = +0.84$) and the net productivity of photosynthesis ($r = +0.52$). A highly reliable positive relationship was established between productivity and signs of nodulation ($r = +0.96$ - with the number of nodules; $r = +0.54$ - with a mass of nodules).

The interdependence of the processes of photosynthesis and nodulation, as evidenced by many highly reliable links between the indicators of nodulation and the efficiency of the assimilation surface, was found, on average, the correlation coefficient was 0.94. In 2010, a direct relationship was determined between the average strength ($r = +0.61$) between the indicators of active symbiotic potential and the net productivity of photosynthesis, the inverse average relationship between the number of nodules and the photosynthetic potential ($r = -0.73$) in the seedling phase, which indicates dependence of the formation of a symbiotic apparatus on the increase in the biological mass of plants in the period of the beginning of intensive growth. During the period of active growth of the assimilation surface of pea plants (budding - flowering), a direct relationship between the average force between the number of

nodules and the leaf area is noted. During this period, the macrosymbiont controls the growth of nodules, the activity of the symbiotic apparatus directly depends on the work of the assimilation surface.

4. Conclusion

- It has been established that the effectiveness of symbiotic nitrogen fixation is determined by the activity of the macrosymbiont, which largely depends on the reserves of productive moisture in the soil before sowing ($r = +0.93$), the content of nitrogen and potassium in the arable layer ($r = +0.72 - +0.90$). In peas, the peak of nodulation is observed in the phase of budding and flowering, with favorable moisture supply, the formation of nodules can occur in the phase of fruit formation).
- Identified significant genotypic differences in the formation of a symbiotic apparatus. The largest number, mass and size of actively functioning nodules, indicators of active symbiotic potential were characterized by the variety samples of peas Blagovest, Batrak, Demos and line 37/03 (Omsky 18).
- It was revealed that the size of the photosynthetic apparatus of pea plants is largely determined by the morphobiological characteristics of genotypes and the hydrothermal growing conditions. The formation of the assimilation surface occurs right up to the flowering phase, in favorable years - to the fruit formation phase. The most powerful photosynthetic apparatus in pea plants was formed under the conditions of 2010, the most varied and effective samples were Demos, L 37/03 (Omsky 18), Omsky 7.
- The productivity of pea agrocenoses was largely determined by the average daily air temperature during the period of full flowering - full ripening, as well as the duration of this period; the amount of precipitation in the period from germination to full bloom. The maximum grain yield of 3.72 and 3.17 tons / ha was recorded in 2008 and 2010, respectively. The greatest increases in yield were characteristic of the variety samples Omsky 7, Blagovest, Demos, L 37/03 (Omsky 18). The last of the varieties was distinguished by the highest stability of this indicator over the years, which indicates its high adaptability.
- The accumulation of protein in the grain is determined by agro-ecological conditions and the genotype of plants. The maximum protein content in the grain and the collection of protein per hectare were noted in 2008 and 2010. High protein grain and the highest protein yield per hectare were provided by variety samples Omsky 9, Demos, Blagovest, L 37/03 (Omsky 18).
- A highly reliable positive relationship is established between plant productivity and photosynthetic parameters ($r = +0.97$ with leaf area; $r = +0.84$ with photosynthetic potential; $r = +0.52$ with net photosynthesis productivity), as well as with signs of nodulation ($r = +0.96$ - with the number of nodules; $r = +0.54$ - with the mass of nodules). Between the indicators of nodulation and the efficiency of the assimilation surface, many highly reliable links were found, on average, the correlation coefficient was 0.94.

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