Practical aspects of the selection of parental forms in the distant soybean hybridization

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Abstract. The article presents the results of research of the genetic collections of cultivated (KF, KB) and wild (KD) soybean of the gene pool of the All-Russian SRI of Soybean. The experimental part of the work was carried out in the laboratory of soybean breeding and genetics of Federal State Budget Scientific Institution “All-Russian Scientific Research Institute of Soybean” (FSBSI ARSRI) of Soybean in the period from 2016 to 2019. Field experiments were laid on the plots of selective crop rotation (Sadovoe village, Tambov district, Amur region) on meadow chernozem soil. The goal of research was to evaluate the source material of wild forms and cultural samples of soybean according to economically valuable traits and photosynthetic activity for selection of high-yielding varieties adapted to local growing conditions. As a result of research, genetic sources of various economically valuable traits were identified from the collection of wild soybean. According to a number of characteristics, soybean varieties were selected from the collections of cultivated soybean KB and KF: Kitrossa, Intriga, Nevesta, Hedi, Tundra with a growing season of 111...116 days and a yield of 3.11...3.37 t/ha, exceeding the standard Dauriya by 0.26...0.52 t/ha. The indicators of photosynthetic process intensity in plant leaves was determined in samples isolated by a complex of economically valuable traits from the collection of wild soybean: KBel-50, KA-1396, KM-695, KM-705, KT-156 (St) and from the best varieties of KB and KF collections. The analysis of the conducted studies made it possible to identify the most promising varieties and forms of wild soybean with the optimal level of activity of photosynthetic processes, which, along with sources of economically valuable traits from the collections of KD, KF, and KB, were included in crossbreeding in 2018-2019.

1. Introduction

Among many methods of present plant breeding, the method of distant hybridization is of great theoretical and practical importance, which is becoming increasingly important every year. The history of breeding research shows that one of the effective ways to use the generic potential of economically valuable traits of plants is interspecific hybridization. The need for widespread use of interspecific hybridization methods in breeding is due to the fact that there is a certain upper limit of genetic diversity, which can be concluded in the gene pool of one species [1]. The composition of the cultivated flora was periodically enriched by the introduction of new wild plant species. As a rule, the use of wild flora provides the introduction into the culture of phylogenetically determined dominant genes that determine ecological plasticity, high homeostasis, resistance to diseases and pests inherent to indigenous species of plants, there is also possibility to transfer genes that control high protein...
content in seeds, early maturation, a large number of seeds with one plant, etc. [2, 3]. The Far Eastern region of Russia is a unique natural bank, where valuable genotypes of numerous species of wild soybean are concentrated, which should be studied and used in the breeding process as a source material in order to improve the adaptive potential of the culture and increase the range of variability in hybrid populations of soybean agrocenosis [4]. No less important is the use of varieties and samples with a high level of plant productivity, an indicator having an integral, multiple-factor property, due to a combination of complex physiological and biochemical processes that occur in the plant body [5]. One of the most important processes that influence the formation of plant productivity is photosynthesis. In this regard, it is necessary to single out samples and varieties of cultivated soybean and forms of wild soybean with high photosynthetic activity to include them in the breeding process [6].

During the formation of organic matter, light plays a key role in determining the intensity of photosynthesis and yield formation. As is known, photosynthesis is a complex process that depends on many factors, such as photochemical and enzymatic reactions, state of the photosynthetic apparatus, and others [7].

As a sensitive indicator of the state of photosynthesis, values are used that indicate the potential quantum yield of photosystem (PS) II, which in turn represents a consisting of several subunits pigment-protein complex integrated into the thylakoid membrane of higher plants. In PSII, using the energy of incident light, a sequence of electron-transport reactions is performed, which leads to the water splitting into molecular oxygen and hydrogen. The water decomposition reaction is an electron source for linear electron transport along the photosynthetic chain [8, 9]. In this case, the primary photosynthetic processes that determine the growth, development of plants, and, as a result, productivity, depend on the amount of light energy absorbed by the collecting pigments. However, not all absorbed energy can be used in photosynthesis, some of its part is emitted in the form of fluorescence or scattered into heat. Fluorescence is the emission of light energy by activated molecules. The information about chlorophyll fluorescence make it possible to determine the effect of light energy absorbed by chlorophyll on the degree of energy use of PSII [10, 11, 12]. With the efficient use of the absorbed energy of light by plants, it is possible to achieve high values of the economically useful part of the yield [13].

In this regard, the goal of our research was to evaluate the source material of wild forms and samples of cultivated soybean according to economically valuable traits and photosynthetic activity for the selection of high-yielding varieties adapted to local growing conditions.

2. Research methods
The objects of research were 97 forms of the collection of wild soybean (KD), collected in different districts of the Amur region (Zeiskiy, Belogorskiy, Arkharinskiy, Blagoveshchenskiy, Mikhailovskiy), 39 varieties and samples of cultivated soybean from the collection of white-flowered forms (KB) and 42 varieties and samples from the collection of violet-flowered forms (KF).

During the study, the best soybean samples by the economically valuable traits were singled out from each collection, which are presented in this article. Based on the 2-year research results in 2016 – 2017, 40 numbers that exceeded the standards by individual and complex features were selected from the collection (KD). In 2018, 22 samples with the best indicators were marked out from the above mentioned numbers at the final stage of research.

The experiments were carried out in 2016–2019 on the plots of field crop rotation of the soybean breeding and genetics laboratory of FSBSI ARSRI of Soybean (Sadovoe village, Tambov region) on meadow chernozem soil. Soybean cultivation was carried out in accordance with the technology developed for the southern agricultural zone of the Amur region [14]. Sowing was carried out from May 20 to May 25, the depth of seed placement was 5...6 cm. The area of one plot was 9 m². The early-ripening variety Lidiya, mid-ripening variety Dauriya and a sample of wild soybean KT-156 selected in the Tambov region were used as standards. Phenological observations and visual evaluations according to economically valuable traits, yield recording and biometric analysis were
carried out in the period of growing season. In the main phases of the development of soybean plants (flowering, bean formation, seed filling), the basic indicators of the photosynthetic process intensity were studied in the leaves of varieties and wild forms using the MINI–PAM fluorimeter: quantum yield of photosynthesis (Y), which characterizes the efficiency of PS II, and quantum efficiency of photochemical conversion of plant energy (F), which determines the photoprotective reaction of plants to the intensity of light radiation. In each phase of the development of plants, 10 measurements were performed on each variety to determine Y and F indicators. Statistical data processing was carried out according to the method of B.A. Dospekhov. The variance analysis of digital material was conducted and LSD (least significant difference) was determined. LSD is a value indicating the limit of possible chance fluctuations in the experiment, which is considered essential at a 5% significance level (LSD$_{0.05}$). [15]. Statistical analysis makes it possible to systematize extensive digital material and prove the reliability of experimental data.

3. Results and its discussion
In the process of studying the collection of wild soybean, the best 22 numbers that exceed the standards for one or a complex of traits were identified (table 1).

Table 1. Characteristics of the best wild soybean forms according to economically valuable traits (2016–2018).

| Line No. | Name of variety, sample | Growing season (days) | Plant height (cm) | Seed weight per plant (g) | Weight of 1000 seeds (g) | Content in the seeds (%) | oil | protein |
|----------|------------------------|-----------------------|-----------------|--------------------------|------------------------|--------------------------|-----|---------|
| 0        | LidiyaSt               | 106±2.1               | 71±3.4          | 44.9±3.6                 | 150.2±7.5              | 19.6±0.5                 | 41.4±0.5 |
| 1        | KT-156 St              | 106±2.5               | 107±2.8         | 35.3±2.8                 | 29.6±2.8               | 12.3±0.4                 | 46.0±0.6 |
| 2        | KBel-50                | 103±2.4               | 105±3.3         | 47.1±2.3                 | 34.5±2.2               | 11.9±0.5                 | 47.6±0.5 |
| 3        | KBel-72                | 101±2.3               | 128±3.1         | 36.7±2.1                 | 28.9±3.9               | 11.9±0.4                 | 47.7±0.3 |
| 6        | KA-349                 | 103±2.5               | 113±2.9         | 41.7±1.9                 | 27.2±3.3               | 11.4±0.3                 | 47.3±0.5 |
| 7        | KA-457                 | 105±2.3               | 121±2.5         | 44.5±1.6                 | 31.3±3.5               | 12.1±0.5                 | 46.6±0.4 |
| 8        | KA-477                 | 105±2.5               | 102±2.6         | 29.6±2.5                 | 29.3±2.9               | 11.3±0.5                 | 48.3±0.6 |
| 11       | KKhab-1                | 113±2.6               | 119±2.5         | 51.3±2.3                 | 38.5±3.7               | 11.8±0.5                 | 47.3±0.5 |
| 12       | KA-1396                | 105±2.2               | 121±2.3         | 48.1±2.1                 | 32.3±3.2               | 11.5±0.2                 | 47.5±0.4 |
| 13       | KA-1413                | 103±2.3               | 120±2.4         | 44.2±2.2                 | 28.8±3.5               | 11.2±0.5                 | 48.4±0.3 |
| 14       | KBI-95                 | 101±2.3               | 124±2.2         | 40.2±1.9                 | 29.2±3.2               | 11.4±0.6                 | 47.7±0.5 |
| 15       | KZ-1236                | 100±2.5               | 129±4.1         | 40.8±2.5                 | 28.1±2.8               | 11.8±0.4                 | 47.6±0.5 |
| 16       | KZ-6332                | 105±2.4               | 128±1.9         | 37.6±2.8                 | 28.9±3.7               | 11.4±0.2                 | 47.9±0.5 |
| 17       | KZ-6337                | 114±2.3               | 115±2.2         | 52.6±2.4                 | 36.7±3.4               | 12.3±0.5                 | 47.1±0.7 |
| 18       | KZ-671                 | 105±2.6               | 129±3.4         | 41.3±2.2                 | 30.2±3.3               | 11.5±0.3                 | 47.6±0.3 |
| 21       | KBI-104                | 104±2.2               | 121±3.1         | 39.4±1.9                 | 28.6±3.7               | 11.4±0.5                 | 48.5±0.5 |
| 24       | KZ-5715                | 107±2.5               | 108±3.3         | 29.8±2.7                 | 28.7±3.1               | 11.1±0.4                 | 49.6±0.5 |
| 26       | KZ-5717                | 107±2.3               | 91±2.8          | 20.1±1.7                 | 28.2±3.9               | 11.2±0.3                 | 48.7±0.4 |
| 28       | KZ-5719                | 108±2.3               | 110±2.3         | 27.7±2.5                 | 28.9±3.5               | 10.9±0.3                 | 49.5±0.4 |
| 30       | KM-695                 | 116±2.7               | 109±1.8         | 55.3±2.4                 | 41.8±3.1               | 11.7±0.4                 | 47.0±0.6 |
| 31       | KM-705                 | 115±2.2               | 110±3.5         | 59.3±2.5                 | 38.5±2.3               | 12.3±0.2                 | 47.0±0.5 |
| 33       | KBI-14                 | 101±2.5               | 126±3.7         | 35.0±2.6                 | 35.3±2.8               | 11.0±0.3                 | 45.0±0.6 |
| 39       | KBI-29                 | 106±2.8               | 115±3.1         | 30.8±2.6                 | 25.6±3.4               | 11.4±0.4                 | 48.4±0.4 |
| 40       | KBI-30                 | 106±2.2               | 115±2.9         | 20.2±2.5                 | 15.1±2.6               | 10.7±0.5                 | 49.2±0.4 |

The duration of growing season in wild forms of soybean ranged from 100 to 116 days. 12 numbers were noted (ripening 1...5 days earlier than the standards), of which the most early-ripening 4 forms were identified – KBel-72, KBI-95, KZ-1236 and KBI-14 with a growing season of 100...101 days.
These forms are of interest in the breeding process for the creation of early-ripening varieties.

The height of plants in the wild soybean forms varied from 91 cm (line No.26 KZ-5717) to 129 cm (lines No.15, 18 - KZ-1236; KZ-671) while the standard cultivated soybean Lidya – 71 cm and the standard wild soybean KT-156 – 107 cm. The highest plant height (121...129 cm) was marked in samples KBel-72, KA-457, KA-1396, KBl-95, KZ-1236, KZ-6332, KZ-671, KBl-104, KBl-14. All isolated forms are sources of high-tallness.

By the seed weight per plant, 15 samples - KBel-50, KBel-72, KA-349, KA-4570, KKhab-1, KA-1396, KA-1413, KBl-95, KZ-1236, KZ-6332, KZ-671, KBl-104, KM-695, KM-705 – exceeded the standard of wild soybean by 2.3...24.0 g and 4 numbers - KBel-50, KBel-72, KM-695, KM-705 - exceeded the standard of cultivated soybean by 2.2...14.4 g. All these forms are of interest as sources of high productivity in interspecific hybridization.

The weight of 1000 seeds in samples of wild soybean ranged from 15.1 to 41.8 g while the standard KT-156 – 29.6 g and the standard Lidya – 150.2 g. According to this indicator, 9 numbers exceeded the standard of wild soybean by 0.6...29.6 g. The best indicators were marked in KM-695 (41.8 g) and KM-705 (38.5 g).

The protein content in the considered forms of soybean ranged from 45.0 to 49.2 %, while the variety Lidya – 41.2 % and KT-156 – 46.0 %. All samples exceeded the standard of cultivated soybean Lidya by 3.6...8.2 % and only 1 number KBl-14 was inferior to the standard of wild soybean by 1.0 %. The maximum protein content was identified in 5 numbers: KBl-104 (48.5 %), KZ-5715 (49.6 %); KZ-5717 (48.7 %); KZ-5719 (49.5 %); KBl-30 (49.2 %). The oil content in the seeds ranged from 10.7 to 12.3 %, which is significantly lower than that of cultivated soybean.

In the process of studying the collection of white-flowered forms, 13 soybean varieties and samples were identified that exceeded the standard Dauriya by 0.13...0.52 t/ha in a number of economically valuable traits and productive indicators, of which 3 soybean varieties (Kitrossa, Intriga, Nevesta) were selected with the best yield indicators. From the collection of violet-flowered forms, 11 numbers were identified that exceeded the standard by 0.08...0.33 t/ha, of which 2 the most highly productive varieties were selected - Hedi and Tundra (table 2).

Table 2. Characteristics of the best soybean varieties KB and KF according to economically valuable traits (2016-2018).

| Name of variety | Growing season (days) | Plant height (cm) | Yield, (t/ha) | Weight of 1000 seeds (g) | Content in the seeds (%) |
|-----------------|-----------------------|-------------------|--------------|-------------------------|--------------------------|
|                 |                       |                   | total        | deviation from the standard | oil          | protein      |
| Dauriya St      | 110±2.5               | 75±3.2            | 2.85±0.22    | 183.9±8.9               | 20.1±0.5     | 38.9±0.6    |
| Kitrossa        | 114±2.4               | 92±2.9            | 3.37±0.21    | 165.4±7.8               | 19.8±0.5     | 40.4±0.5    |
| Intriga         | 112±2.3               | 83±2.7            | 3.12±0.17    | 154.9±8.5               | 18.6±0.5     | 39.5±0.4    |
| Nevesta         | 116±2.3               | 77±3.3            | 3.26±0.19    | 170.7±7.6               | 18.9±0.4     | 39.9±0.3    |
| Hedi            | 113±2.5               | 74±3.1            | 3.18±0.17    | 195.2±8.1               | 18.5±0.6     | 41.3±0.5    |
| Tundra          | 111±1.9               | 72±2.8            | 3.11±0.11    | 189.1±7.4               | 21.3±0.3     | 39.7±0.5    |

Soybean varieties Kitrossa, Intriga, Nevesta, Hedi, Tundra with a growing season of 111...116 days and a yield of 3.11... 3.37 t/ha exceeded the standard Dauriya by 0.26...0.52 t/ha and surpassed it in protein content in seeds by 0.6...2.4 %.

The indicators of the photosynthetic process intensity in plant leaves were determined in samples isolated by a complex of economically valuable traits from the wild soybean collection: KBel-50, KA-1396, KM-695, KM-705, KT-156 (St) and in the best varieties from the collections of KB and KF: Kitrossa, Intriga, Nevesta, Hedi, Tundra, with the prospect of using the best ones in the following breeding process to create highly productive soybean varieties with an optimal level of photosynthetic
activity.

It is known that further photosynthetic processes of the whole plant organism depend on the quantum energy of light absorbed by the light-harvesting complex of plants. In our studies, the indicator of the quantum yield of photosynthesis varied significantly depending on the studied varieties, forms, and phases of soybean plant development (table 3).

The analysis of the photosynthetic process intensity made it possible to establish that the indicator of the quantum yield of photosynthesis in wild soybean forms in all considered phases of growth and development (flowering, bean formation, seed filling) varied from 0.449 to 0.791 relative units. This indicator reached maximum values during the seed filling phase. It was the highest in KBel-50, KA-1396 (0.787 and 0.791 relative units).

Table 3. Quantum yield of chlorophyll fluorescence (F) and photosynthesis (Y) in the plant leaves of wild soybean forms according to development phases 2018.

| Name of sample | Flowering phase of soybean | Phase of bean formation | Phase of seed filling |
|----------------|---------------------------|-------------------------|----------------------|
|                | F   | Y    | F    | Y    | F    | Y    |
| KT-156 St      | 709.7 | 0.478 | 333.1 | 0.679 | 368.2 | 0.791 |
| KBI-50         | 699.5 | 0.449 | 393.9 | 0.628 | 343.4 | 0.787 |
| KA-1396        | 708.9 | 0.467 | 368.5 | 0.626 | 387.1 | 0.791 |
| KM-695         | 744.0 | 0.524 | 371.9 | 0.645 | 416.1 | 0.776 |
| KM-705         | 736.9 | 0.513 | 405.5 | 0.625 | 421.5 | 0.772 |
| LSD<sub>0.05</sub> (Least significant difference<sub>0.05</sub>) | 6.4 | 0.05 | 5.3 | 0.04 | 4.2 | 0.06 |

The highest values of the quantum yield of chlorophyll fluorescence were noted during the flowering phase (744.0 and 736.9 relative units) in the wild soybean forms KM-695 and KM-705.

In the studied varieties, the indicator of the quantum yield of photosynthesis varied from 0.471 to 0.749 relative units depending on the variety and phase of plant development (table 4).

Table 4. Quantum yield of chlorophyll fluorescence (F) and photosynthesis (Y) in the plant leaves of soybean varieties according to development phases 2018.

| Name of variety | Flowering phase of soybean | Phase of bean formation | Phase of seed filling |
|----------------|---------------------------|-------------------------|----------------------|
|                | F   | Y    | F    | Y    | F    | Y    |
| Kitrossa       | 524.1 | 0.542 | 379.7 | 0.644 | 464.8 | 0.746 |
| Intriga        | 653.5 | 0.481 | 360.1 | 0.657 | 331.8 | 0.749 |
| Nevesta        | 627.1 | 0.471 | 409.5 | 0.573 | 322.7 | 0.731 |
| Hedi           | 571.7 | 0.509 | 407.1 | 0.574 | 312.9 | 0.713 |
| Tundra         | 758.6 | 0.564 | 431.6 | 0.596 | 333.2 | 0.739 |
| LSD<sub>0.05</sub> (Least significant difference<sub>0.05</sub>) | 5.9 | 0.03 | 6.2 | 0.03 | 5.8 | 0.05 |

This indicator reached its maximum values during the seed filling phase in all varieties, as well as in samples of wild soybean. Its highest values were observed in soybean varieties Intriga and Kitrossa (0.749 and 0.746 relative units).

The highest values of the quantum yield of fluorescence were noted in the flowering phase in all varieties. The varieties Intriga (653.5 relative units) and Tundra (758.6 relative units) reached the maximum value of this indicator.
As a result of the conducted research, the common tendency was found for all forms and varieties of soybean, namely, an increase in the quantum yield of photosynthesis (Y) from the soybean flowering phase to the seed filling phase, which indicates a gradual increase in solar energy absorption by the leaf surface of varieties and forms of wild soybean. Therefore, just during the seed filling phase, the photosynthetic apparatus of soybean plants works most actively, which contributes to the active accumulation of nutrients and their outflow from leaves to the generative organs.

When determining the quantum yield of chlorophyll fluorescence, the opposite tendency was noted, namely, a decrease in this indicator from the flowering phase to the seed filling phase, which indicates a gradual decrease in not absorbed from solar energy photons emitted in the form of fluorescence. During the flowering period, high values (F) indicate a weak use of light quanta by chlorophyll in this period, however, by the seed filling phase, a significant decrease in this indicator is observed in all samples and forms of soybean, since during this period the solar energy is actively converted into the biochemical energy of organic matter. Therefore, the low indicators of quantum yield of chlorophyll fluorescence and the high values of quantum yield of photosynthesis in the seed filling phase show the high efficiency of photosystem II in soybean leaves and increased photosynthetic activity. In our research, the analysis of the studied material made it possible to identify the best varieties - Kitrossa, Intriga and Tundra, and the samples of wild forms of soybean - KBel-50, KA-1396 and KM-705, with an optimal activity level of photosynthetic processes and a high coefficient of solar energy use.

4. Conclusion
In the process of studying the breeding material, according to individual and complex traits, the best varieties and samples of wild soybean from the collections of KD, KB, and KF with a high level of photosynthetic activity were identified. In 2018–2019, they were included in various crossbreeding variants. So, in 2018, hybridization was carried out and offspring was obtained by 17 combinations, of which 10 - natural (5 intraspecific and 5 interspecific) and 7 - artificial interspecific hybridization. In 2019, the total number of crosses amounted to 22 combinations obtained by natural hybridization, of which 5 were from crosses of wild soybean with cultivated one, 6 – G.max x G.max, and 11 – intermediate F1 hybrids with cultivated soybean. All obtained material will be further studied according to the scheme of the complete breeding process.

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