

BREEDING PULSES TO IMPROVE ADAPTIVE TRAITS UNDER CONDITIONS OF GENERAL WARMING

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Summary. The importance of leguminous crops as a source of high-quality protein, macro- and microelements, dietary fiber, vitamins, unsaturated fatty acids and antioxidants is substantiated. Their significant positive role in maintaining high soil fertility due to biological nitrogen fixation is shown. Methods of breeding of soybean, pea and chickpea at the Plant Breeding and Genetics Institute are described. The characteristics of the bred varieties by elements of productivity, resistance to adverse abiotic environmental factors, biochemical parameters of seeds are given.

Keywords: soybean, pea, chickpea, drought resistance, initial material, breeding methods

Introduction

In world agriculture, the group of legumes ranks second after cereals both in terms of sown areas and gross yields. Their role is due to a number of important positive signs. Firstly, they provide high-quality raw materials for the preparation of both food and feed products. Their seeds contain 25-40% of protein with a complete amino acid composition, which has a preventive effect against a number of diseases that are intensively spreading in the late twentieth and early twenty-first centuries. In addition, their seeds are rich in a significant amount of biologically active components such as vitamins, minerals, trace elements, unsaturated fatty acids, phospholipids, essential aminoacids, dietary fiber, phytochemicals (polyphenols, terpenoids, carotenoids, phytosterols), antioxidants. Such products are characterized by therapeutic and prophylactic properties that ensure the bioregulatory and immunoregulatory functions of the human body, as well as its adaptation to environmental factors.

The second important feature of legumes is the ability to fix nitrogen from the air and, due to this, almost completely provide this element for the formation of their own crop. Soybean, pea, chickpea, lentil bind 100-150 kg/ha of nitrogen in the active ingredient during the growing season, which is equivalent to the introduction of about 300 kg of nitrate into the soil.

Global warming, which leads to an increase in temperature and long rainless periods during the growing season of plants, significantly reduces grain yield, up to its complete loss. This situation necessitates the introduction of drought-tolerant species that give economically justified yields even under adverse meteorological conditions. Therefore, the use of lentil and chickpea, which are quite drought-resistant, makes it possible to reduce the loss of agricultural products in dry seasons.

Intensive introduction of cereal and legume crop rotations will also lead to the improvement of the environment and the preservation of soil quality. The UN's recognition of the importance of this group of crops for humanity is the celebration of 2016 as the International Year of Pulses. Based on a set of positive signs, their areas are constantly growing. The greatest dynamics is observed in soybean. If in 2000 it was sown on 74.3 million hectares, then in 2014 the area reached 117.7, in 2019 – 120.5, and in 2022 – 133.8 million hectares. During this period, its yield increased from 2.11 t/ha to 2.86 t/ha. The area under kidney bean has expanded by 50% this century, chickpea by 47%, cowpea by 67.4%, and lentil by 44%. The intensive growth of the world's population of

people indicates that the positive trend of growth in the production of leguminous crops will grow in the future. To this end, the world's leading centers for breeding leguminous crops, such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Center for Agricultural Research in the Dry Areas (ICARDA), the International Institute of Tropical Agriculture (IITA), are working on the creation of high-yielding, adaptive, technological varieties, using both traditional breeding methods (artificial hybridization with subsequent selection of transgressive forms) as well as the latest methods that allow to more accurately identify valuable plants, the descendants of which can serve as a base for new varieties. To obtain the original source material, marker selection (MAS) is intensively used, the essence of which is to identify certain sections of DNA (genes) that are associated with the expression of a morphological, biochemical or physiological characteristic. For most legumes, genetic maps have been built, that is, the position of genes on the chromosome has been determined, which makes it possible to control their movement in the offspring at the early stages of the breeding process. The method of creating so-called MAGIC hybrids (multi-parent advanced generation intercrosses) is widely used in the world. The parental forms in this scheme are recombinant lines or hybrid offspring obtained from two-component crosses. The lines isolated from such complex hybrid populations combine a valuable complex of economic and adaptive traits.

Global warming, which the current generation is witnessing, has posed a number of new challenges to the agricultural industry. The constant increase in air and soil temperatures, the increase in inter-rainy periods and the presence of prolonged droughts during the growing season of plants lead to significant yield losses. Therefore, at this stage, the main efforts of breeders are focused, first of all, on the creation of varieties that are highly adaptive to high air temperatures and lack of moisture in the soil. We solve the same goal in the process of breeding soybean, pea, chickpea and lentil.

Materials and methods

In field and laboratory experiments, a large set of collection and breeding forms of soybean, chickpea, pea, as well as all varieties bred by PBGI – NCSCI, which are included in the register of plant varieties suitable for distribution in Ukraine, were analyzed. The collection material was sown in single-row plots 1.5 m long with frequent standards. Ecological, competitive and preliminary testing was laid in five repetitions for plots of 10 m². During the growing season, the main phases of plant development were noted and the necessary measurements and observations were carried out.

The soils of the zone are medium-humus chernozems, the thickness of the humus layer reaches 40–50 cm, the reaction is neutral or slightly alkaline (pH 6.0–7.2). The average air temperature is +10.6°C, the average precipitation is 484 mm. The temperature regime is favorable for the cultivation of this group of crops, but dry conditions during the growing season, as a rule, inhibit plant growth and reduce their productivity.

Results and discussions

These days, soy plays a crucial role in providing people, animals, and poultry in the world with high-quality protein. In recent decades, a similar situation has developed in Ukraine. If in 2000 it was sown with 60.6 thousand hectares, in 2005 – 421.7, in 2010 – 1037, and in 2017 the area reached 1982 thousand hectares. Since 2013, the seed yield has exceeded 2 t/ha, and in some years it reaches 2.5–2.7 t/ha. For a 45-year period of breeding work at our institute, 35 varieties of soybean of different ripeness groups have been bred, which were recommended for cultivation in Ukraine, Russia and Belarus. The successes achieved were obtained due to the use in hybridization of a large amount of collection material that came from different countries of the world, as well as a significant number of tested lines of hybrid origin of early generations. It should be noted that the breeding nursery, as a rule, included 15-20 thousand lines.

Studies have shown that under dry conditions, seed productivity is most closely related to the intensity of development of the aerial part of the plant, the diameter of the stem at its base, and the number of beans per plant. Thus, the obtained data confirm that the drought resistance of soybean can be determined by the accumulation of aboveground mass under conditions of water deficit.

The obtained experimental results testify to the high heat resistance of soybean plants, which significantly exceeds this indicator in cereal crops. Under conditions of elevated temperatures, a significant amount of free proline accumulates in soybean leaves, the level of which indicates the resistance of the variety to this factor. Genotypic variability in the water-holding capacity of leaves was also revealed. According to the complex of signs, we found varieties of domestic origin resistant to lack of moisture. Among the collection set, a rather drought-resistant form of PI 416937 was distinguished, which is characterized by an increased level of leaf watering, is able to better retain turgor, transpiration and the rate of CO₂ metabolism under water stress compared to other varieties. In field experiments in the arid conditions of the steppe zone of Ukraine, domestic varieties Arcadia Odes'ka, Charivnytsia Stepu, Palmyra, Odes'ka 150, Khadzhibey, Eldorado, Faeton, as well as foreign varieties such as Hardin 91 (USA), NSL 315110 (Serbia), F 91-1157 (Hungary) were distinguished by increased productivity [Sichkar, Pasichnyk, 2018].

The natural background of our zone makes it possible to objectively assess the level of drought resistance of soybean varieties of various breeding institutions. Increased adaptability to the lack of moisture in the soil and high air temperatures was noted by the varieties Arcadia Odes'ka, Vasylykivska, Altair, Yatran', created at the Plant Breeding and Genetics Institute, Romantica, bred at the Institute of Plant Production, Sprint from the Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine, Valiuta and Yuvileina from the Kirovograd State Agricultural Experimental Station and Proteinka from the Institute of Field and Vegetable Growing (Serbia, Novi Sad). We believe that these varieties are valuable carriers of genetic factors that determine adaptability to arid environmental conditions.

It has been established that under dry conditions, a higher yield is formed with an optimal combination of various elements of productivity and economically valuable traits, among which the above-ground mass of plants, the number of beans and seeds per plant are of the greatest importance [Sichkar, 1989]. Our long-term data indicate that the color of pubescence, the shape of the leaves, the type of growth have little effect on the level of adaptability in steppe conditions. For example, the Arcadia Odes'ka has shown high adaptive potential for more than 25 years. It belongs to the early maturing group, is characterized by a determinant type of growth, branches well and has an increased above-ground mass. On the other hand, the Vasylykivska and Romantika varieties are non-determinant, early ripening, with fewer side branches. They also stand out for their high level of adaptability to arid environmental conditions.

The determinant type of growth is due to the action of the dominant Dt1 gene (Dt1, Dt1 and Dt1, dt1). The indeterminate genotype carries this gene in a recessive state (dt1, dt1). In addition, there is also a semi-determinant pattern of growth, which is intermediate between the above and is controlled by the dominant Dt2 gene, which is expressed only in the presence of the Dt1 gene. Depending on the presence of a particular gene, the growth and formation of the generative organs of soybean plants takes place.

It should be noted that the height of determinant forms varies greatly and depends significantly on the presence of photoperiodic reaction genes that affect the onset of flowering. To obtain tall forms, the Dt1 gene must be combined with a complex of photoperiodic genes. In non-determinate varieties, new nodes are formed during the entire growth period. Under our conditions, the adaptive properties of modern soybean varieties are approximately equivalent in both cultivars, although there is a discussion regarding this conclusion. The varieties we bred do not differ significantly in productivity and adaptive potential depending on the type of growth. Such new non-determinant varieties as Syaivo, Danko, Antares, Pivdenna Zorya, Odesytka, semi-determinate -

Rusa, Feniks, Orfei, Euridika, Aurora, Zmina and highly determinate - Farwater, Don'ka, Melpomena, Symphonia, Serenada are characterized by high yield potential under optimal growing conditions and belong to the group of drought-resistant. In 2023, at the demonstration site of the Poltava State Agricultural Research Station the yield of the Euridika reached 5.36 t/ha, the Aurora – 4.86 t/ha and the Zmina – 4.57 t/ha. At the demonstration site of the Institute of Fodder and Agriculture of Podillya in the same year, the yield of the above varieties was 2.07; 2.15 and 1.97 t/ha, respectively, and the varieties Serenada (2.58 t/ha), Vasylykivska (2.55 t/ha), Feniks (2.52 t/ha), Odesytka (2.36 t/ha) stood out in this location.

The level of drought resistance significantly depends on the peculiarities of the formation of the leaf apparatus of plants. In our experiments under dry conditions, it was shown that the optimal leaf surface area is formed in varieties of different precocity. The dynamics of its growth is s-shaped, a positive relationship with yield was observed only in early ripening varieties. In the process of breeding, it is important to select forms in which the leaf area increases very quickly during the vegetative period, that is, before flowering, and with the beginning of the formation of beans, the growth slows down and the synthesized plastic substances are more rationally used by generative organs.

Our research has shown that it is possible to create soybean varieties that are highly adaptable to arid conditions and that branch well. Such an example is the variety Arcadia Odes'ka, which was in the state register from 1986 to 2010. It stood out for its high adaptive potential, formed a significant number of lateral branches under arid conditions, and had high protein content in the seeds. The variety Arcadia Odes'ka was widely involved in hybridization, its hereditary material is present in the pedigree of such varieties as Yatran', Antares, Rusa, Symphonia, Orfei, Euridika, Zmina.

The level of drought resistance is also significantly influenced by the duration of individual phases of ontogeny. As a rule, breeders try to breed varieties that move early from vegetative to generative development, that is, they bloom quickly. A particularly significant relationship was found between the duration of the "seedling-flowering" phase and the level of drought resistance during the onset of drought in the second half of summer. Our studies in the arid conditions of the Steppe, where drought occurs almost annually in July-August, have shown that the realization of the yield potential of soybean varieties by 89–93% depends on the interaction of precipitation and active temperatures. Most of all, these factors affect from the end of May to July, when intensive growth, flowering and setting of beans occurs. The most significant for the formation of yields were the air temperature in May and the amount of precipitation in July.

Thus, the above experimental data indicate that the adaptive potential of a variety is a rather complex trait, which depends on the genotype of the variety and the conditions under which it is grown. Successful breeding to improve it is complicated by the fact that it is formed as a result of the action of the entire set of genes. Despite this, there are key indicators on the basis of which breeders make selections to improve certain traits that are part of this complex. Among them are the water-holding capacity of leaves, a more developed root system or its individual parts, the nature of the combination of photoperiodic reaction genes, and the genetically determined efficiency of water use by plants. With an optimal combination of the above traits during the growing season, plants form leaf and root surfaces that meet the prevailing conditions, they maintain high levels of photosynthesis, and transpiration and normal water balance in tissues. An important step in improving drought tolerance of soybeans is to identify collection specimens in which there is a slower withering of the above-ground mass under water stress. Physiological studies have shown that this trait is due to a very low rate of transpiration. To breed highly adaptive varieties, it is necessary to combine several traits in one genotype by hybridization, in which the passages of the main phenological phases will be synchronized with the natural factors of a certain ecological zone.

Pea is essential in the agricultural sector of Ukraine. At the end of the last century, its area was about 1.5 million hectares, and the gross harvest exceeded 3 million tons. We believe that in

order to ensure the stable development of the agricultural sector in the country, it is necessary to restore pea to the level of the end of the twentieth century.

Our pea breeding program is based on the use of genes that effectively affect the architectonics of plants (*def* – seed shedding, *af* – leafless type, *deh*, *Stb* – stem determinant), which significantly improves the manufacturability of the crop and contributes to an increase in yield. In recent decades, much attention has been paid to the creation of so-called "leafless" varieties, in which, as a result of the *afila* mutation, the leaves turn into tendrils, with which individual plants interlock with each other and thus maintain an upright position. Modern varieties of this type have well-developed whiskers, which are also an important photosynthetic organ.

Obtaining new source material is achieved by hybridization of specially selected parental forms, which must necessarily bear features that significantly affect resistance to adverse environmental factors. The breeder's task is to combine them in a single genotype, which will be characterized by improved overall adaptability. In addition, we involve genotypes that are characterized by high seed productivity in crossing. As a rule, adaptive parental components come from the steppe zone of our country, and highly productive ones come from European countries.

To date, 63 varieties have been included in the state register of varieties suitable for distribution in Ukraine, about half of which were created in our country. The Plant Breeding and Genetics Institute is the owner of 7 varieties, among which Cruise stands out for its high level of drought resistance. The White Angel variety is characterized by significant resistance to lodging and is able to yield a yield of 5 t/ha under optimal growing conditions.

One of the ways to stabilize yields can be winter sowing of peas. Under the conditions of the steppe zone of Ukraine, most moisture in the soil accumulates in early spring. During this period, its reserves reach 130-150 mm, and in some years 160 mm. This moisture is enough to form a satisfactory crop, especially with the introduction of moisture-saving technologies.

During 2017–2023, in the conditions of the central zone of the Odessa region, we conducted a study on the autumn sowing of peas, using cold-resistant varieties for this - Serbian Moroz and French Enduro and Balltrap. They showed that with this technology, the growth and development of peas are significantly accelerated and they ripen 18-20 days earlier than sown in spring. So, in 2018, the phase of full ripening of the above varieties began on the first of June. In addition, the yield of such crops, depending on the variety, was 10-15% higher compared to the optimal sowing time in spring. It is important to note that global warming, which is especially evident in the steppe zone of Ukraine, contributes to the introduction of this technology of growing peas. Winters have become milder in recent decades, and spring comes earlier.

By crossing cold-resistant varieties of foreign selection and domestic ones recommended for cultivation during spring sowing, we have created a valuable source material for the selection of recombinant lines that are adapted for winter sowing. The first variety of this type called Feniks odes'kyi has already been submitted for state examination.

In the context of climate change, chickpea is gaining popularity – an important heat- and drought-resistant leguminous crop. In particularly dry years, which have recently become more frequent, chickpea competes well in productivity with pea [Magbool et al., 2017].

Its protein stands out for its unique value, it is completely balanced in terms of the content of essential amino acids, is characterized by a therapeutic effect, especially protects against such diseases of our time as cardiovascular and oncological. In addition, its use in food helps to reduce blood cholesterol levels, prevents the development of osteoporosis, atherosclerosis, diabetes mellitus, obesity, and increases the overall adaptive properties of the body. In addition to high-quality protein, chickpea seeds contain many vitamins, minerals, and other biologically active compounds. Particularly valuable components of its seeds are isoflavones – compounds of a polyphenolic nature.

18 varieties of chickpea are recommended for cultivation in Ukraine, 7 of which were created in the PBGI – NCSCI – the leading chickpea breeding institution in the country. The

breeding program is focused on the creation of large-seeded varieties with light seeds and a high coefficient of boiling, which are in great demand in the world market. These are the characteristics of the Triumph, Odyssey and Skarb varieties. These varieties, as well as Budzhak and Dostatok, were created by the method of multicomponent crosses (there are 3-4 parental forms in the pedigree).

In our institute, chickpea breeding began in 1995. It is based on collection material obtained from the International Research Center for Semi-Arid Tropics (ICRISAT, Patancheru, India) and the Center for Plant Genetic Resources of Ukraine (Kharkiv). Over the past period, more than 3 thousand collection forms have been analyzed for economically valuable traits and 12 varieties have been created. The accumulated long-term information allows us to form the main indicators of the model of a highly adaptive variety for the arid zones of our country. It is based on phenological, physiological, biological traits, as well as the genotype-environment interaction [Sichkar et al., 2023].

In the process of breeding work, it is necessary to strive for the formation of erectoid plants, in which the lateral branches depart from the main stem at an angle of less than 15°C. The height of the plants should be 50–60 cm; the height of attachment of the lower bean should be 15–17 cm. Vertically oriented leaves with a reduced width are much better able to transmit sunlight into the middle and lower tiers of the plant. The growth of the leaf surface should be synchronized with the general development of the above-ground mass, which is an important criterion for selection for increased productivity. The ratio between the total biological weight and the weight of the seeds (harvest index) should be within 0.5.

For production, it is necessary to create varieties of different ripeness groups, which allows to more effectively use natural factors for the formation of yields, especially precipitation, and better use agricultural machinery. According to the duration of the growing season, five groups can be distinguished: very early (<75 days), early (76–80 days), medium (81–100 days), late (101–110 days) and very late (>110 days). For the conditions of Ukraine, the most favorable are early and mid-season varieties, the duration of the growing season of which allows timely harvesting and preparing the soil for sowing winter crops. The creation of early ripening varieties helps to avoid drought and high temperatures at the end of flowering and in the process of filling seeds. In the process of breeding, it is necessary to reduce the duration of the growing season due to the phase "germination - beginning of flowering" in order to have a longer time for the formation and filling of seeds.

Conclusions

Leguminous crops play an important role in the formation of food and feed resources of both our planet and Ukraine.

In the context of global warming, the main efforts of breeders should be directed to the creation of varieties resistant to abiotic and biotic environmental factors.

Particular attention should be paid to drought resistance, which depends on the level of development of the root system, the duration of the growing season, the effectiveness of stomata, the leaf surface area, the expression of specific genes and the biosynthesis of secondary metabolites (proline, abscisic acid).

Models of soybean, pea and chickpea varieties for arid conditions of the steppe zone of Ukraine are proposed, which include such parameters as the type of growth, the duration of the growing season, the area of the leaf surface, the optimal number of lateral branches, and the size of seeds.

The main method of selection is intervarietal hybridization of selected parental forms. Its effectiveness increases significantly with the use of crossing components that differ in ecological and geographical origin, productivity elements and the duration of the growing season. Significant genotypic variability is formed when using multicomponent crosses.

To create source material highly adapted to arid zones, it is necessary to combine traditional, marker and genomic breeding methods. The use of genetic markers makes it possible to control the presence of a certain locus in a number of subsequent generations.

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