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Nutritional Value of Grain Legumes in Relation for Global Food Security

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Based on the research results obtained by the authors and other researchers, the importance and necessity of increasing the production of leguminous crops as an important source of food for the population of our planet are substantiated. It is proved that the varieties of these crops created in our country as well as the soil and climatic features allow us to expand their acreage significantly, which will positively affect the entire agricultural complex. The methodology adopted for this research comprises field and laboratory procedures used in breeding legume crops. The genotypes of the world collection of soybean, pea, chickpea and lentil were tested for yield, drought resistance, protein content and seed quality. The paper provides a description of the varieties of soybean, pea and chickpea created in the Plant Breeding and Genetics Institute, the world gene pool of these crops is characterized, which is most adapted to the steppe conditions of Ukraine. The most common methods of processing commodity seeds into food ingredients characterized by high therapeutic and prophylactic properties are described. The results can be applied in further breeding work with leguminous crops which should be aimed at developing the complex of adaptive traits and improving the chemical composition of seeds. In this paper we demonstrated the significant potential of legumes for solution of the future sustainable nutrition problems.

Keywords: leguminous crops, yield, drought resistance, functional food products

1 Introduction

Plant and animal protein resources are the basis for the development of human civilization at all stages of its history. The quality of people's life, as well as its duration, state of health, and ability to work largely depend on their quantity. Despite significant efforts in almost all countries, the problem of ensuring good nutrition has not been solved to this day. In addition, studies show that by 2050, the world's population will grow to 9–10 billion people, that is, the increase is more than 2 billion. On the other hand, the level of nutrition in developing countries is significantly improving. China, India, and a number of African countries are constantly increasing food production, while raising the level of its quality. A recently published review carried out under the auspices of Food and Agriculture Organisation (FAO) in collaboration with the International Fund for Agricultural Development (IFAD), the United Nations Children's Fund (UNISEF), the World Food Programme (WFP) and the World Health Organization (WHO) shows that undernutrition rates in the world have not been decreasing in recent years. This is due to population growth, low economic development, climate change, and an increase in extreme climate events. Therefore, to date, 827 million people suffer from malnutrition (Alexandratos, Bruinsma, 2012). In addition, 2 billion of the inhabitants of our planet experience severe or moderate levels of food instability (Pulses: Nutritious Seeds for a Sustainable Future, 2016). For example, in 2016/2017 India imported 7 million tons of leguminous crops to meet their needs (Jacobs, 2018).

Leguminous crops play a crucial role in the nutritional balance of our planet. Thanks to them, millions of people are provided with normal nutrition, especially in developing countries. In addition, in recent decades, an increasing number of the population consumes products based on them, which helps to reduce dependence on such diseases of today as cardiovascular, cancer, diabetes, dysbiosis, anemia, diseases of the genital and urinary systems, kidneys and liver. The consumption of dishes

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from the seeds of this group of crops helps to improve immunity, normalizes functioning of the gastrointestinal tract, has a positive effect on maintaining body weight, which allows to maintain a beautiful figure and prevent premature aging. Such an effect on the human body can be explained by the biochemical composition of their seeds. Firstly, it stands out for its high content of easily digestible protein, which is marked by an increased level of essential amino acids. This composition of products makes it possible to replace expensive meat and dairy products only with health benefits, since plant ingredients are devoid of cholesterol and contain little fat. At the same time, it should be noted that the more new information appears about the functional features of seeds of leguminous crops, the more its use for food purposes increases. So, in recent years, it has become known that nitrates, nitrites, radionuclides and other substances toxic to health almost do not accumulate in the aboveground mass of these plants. The seeds of cultivated varieties of leguminous crops contain 24–45% protein, it is characterized by high taste, quickly swells and boils, and has a pleasant aroma. Products from these crops are rich in isoflavones, which have a preventive effect on the cardiovascular system and cancer, improve the elasticity of blood vessels, lower blood pressure and inhibit the accumulation of platelets. They are of particular importance for children and adolescents, who are intensively increasing body weight and have high energy expenditures. Leguminous crops, especially lentil and chickpea, play a significant role in providing the population with such important trace elements for health as selenium, iron and zinc. Therefore, a number of studies have clearly proven that diets based on a mixture of products from legumes and cereals and enriched with meat are much more beneficial for health than the consumption of meat or milk in its pure form. Seeds of leguminous crops contain 33.7–51.3% of available carbohydrates. Their important feature is that they include such compounds as oligosaccharides, polyhydric alcohols, resistant starch, which are a nutrient medium for a group of beneficial microorganisms that live in the large intestine and perform bioregulatory functions. They ferment nutrients that have not been absorbed in the upper gastrointestinal tract, forming a variety of chemical compounds that have a positive effect on the human body. Bacteria such as Lactobacillus, Eubacterium, Bifidobacterium secrete biologically active components that ensure the performance of the bioregulatory function of food products. Thus, 100 g of lentil seeds contain an average of 4.1 mg of raffinose, 1.4 mg of polyhydric sugars, 62 mg of oligosaccharides (kestose, nystosis, soluble and insoluble fiber) and 7.5 mg of resistant starch. Thus, the complex of prebiotic carbohydrates selectively stimulates the growth and activity of bacteria, which have a significant impact on maintaining a high level of health and improving the adaptability of people.

A positive value for the prophylactic effect of food products from the seeds of leguminous crops against cardiovascular diseases is the high content of potassium and magnesium in it. When eating meat as a source of high-quality protein, the body simultaneously receives an excess amount of fat with the presence of saturated fatty acids in it, which are the cause of many diseases associated with the cardiovascular system. In addition, it should be remembered that for the synthesis of one kilogram of animal protein, it is necessary to spend 10–15 kg of vegetable protein. This is the main reason for the high cost of livestock products. Despite this argument, the use of leguminous seeds for food purposes in the world varies greatly – from 34.3 kg.year^{-1}.person^{-1} in the country of Niger to 0.031–0.053 kg in Uzbekistan, Romania, Poland. On average, each inhabitant of our planet consumes about 21 g of leguminous seeds per day, which is clearly not enough to maintain a sufficient level of health. Due to this amount, only 6% of protein and 3% of energy are covered. One of the most important factors in this situation is the competition of high-protein ingredients of plant and animal origin in the food market. At the end of the last century and the beginning of this century, large-scale broiler poultry farming, beef cattle breeding and fish farming are intensively developing in many countries. This has led to lower prices for livestock products in many areas of the world. Thus, during this period, the price ratio was not in favor of leguminous crops. Only in countries where the cost of chicken meat has not decreased, there is an increased consumption of leguminous crops. This trend was also facilitated by a significant increase in household incomes, especially in countries such as China and India.

In the early 1970s, the total harvest of seeds of leguminous crops was 3.5% in relation to cereals. Subsequently, this ratio gradually decreased to 2.8% in 2014. This trend is explained by a more significant increase in grain yields. While the average yield of legumes in the early 1970s was about one-third of cereals, in 2014 it fell to 25%. In 1971, these figures were at the level of 670 and 1789 kg, in 2014 – 929 and 3,784 kg, respectively. Currently, there is a significant gap between the real and potential yields of a number of leguminous crops, which is due to the insufficient level of agronomic technologies, lack of new varieties, poor seed quality, significant losses from pest and disease damage.

At the International Conference on Pulses, which was held in Colombo (Sri Lanka) in May 2018, it was clearly stated that the pulse sector will grow intensively in the coming years. Its participants appealed to the world community

in order to improve cooperation and logistics in this area of activity.

Germinated seeds of leguminous crops are also of significant nutritional importance, which are richer in trace elements, especially zinc and copper, vitamins and easily digestible protein components.

Legume seeds can be used in various forms, as an independent dish or as additives to other types of cereals, herbs, vegetables, in the form of soups, pate is prepared from it, for example, the world-famous hummus. It can be prepared from almost all legumes. Unripe seeds can be frozen and kept in this form for a long time.

Among of the 10 foods recommended for longevity, half belong to the legume family, namely lentil, soybean, chickpea, peanut, and bean, especially those with black seeds. Such data were obtained by studying the nutritional characteristics of people in the blue zone (Sardinia, California, Costa Rica).

Significant climate changes that have been observed in recent decades affect agriculture. A constant increase in temperature in the spring and summer, long inter-rainy periods during the growing season of the main crops, precipitation in the form of showers, thunderstorms and hail, frequent warming during the winter indicate that farmers are faced with almost a new type of climate, which manifests itself especially in the steppe zone of our country, where the tendency to increase the effect of weather factors is clearly realized, that cause soil and air droughts.

Scientists at the Louis Maximilian International University predict that in the future, climate change in Europe will lead to longer and more severe droughts. During the winter months, there will be a lot of rainfall, but in the summer it will decrease to a minimum. Recently, climatologists warned that 2022 will be one of the hottest years on Earth. According to the United Nations (UN), in the coming decades, crop yields in the world may decrease by about 30% due to climate change, while the demand for food will increase by 50%.

Over the past 30 years, the average annual air temperature has increased by 1.5 degrees: in the cold period, primarily January–February, by 2–2.5 degrees, in the warm period – by 1.5–2 degrees, especially noticeable in July and August. At the same time, the duration of the spring and autumn periods has significantly decreased. For example, in 2019, there was no meteorological winter in Ukraine at all. Precipitation patterns are also changing, although not as significantly. The efficiency of rain due to the faster evaporation of moisture decreases as it has become warmer. As a result, there are more arid phenomena in the summer, which reduce or destroy the yield. It should be noted that due to the scarcity of water on our planet, large gains of agricultural production is lost globally (Bayer, 1982).

The major pulse crops, pea, chickpea, lentil, cowpea, were domesticated in the about 10 thousand years ago in the zone of the so-called "Fertile Crescent" – the old Levant, where the first land cultivation was born. It is also called "founder crops". This includes the territory of Cyprus, Lebanon, Izrael, Syria, Iraq, the south-eastern Turkey, the south-west Iran and the north-west Jordan. It is the center of the domestication of 8 main crops, including wheat, barley, flax and the most called leguminous crops. In the IV–I centuries BC, more than 10% of the population of our planet lived there, which became about 120 million people. This region was characterized by fertile soils and the periodic presence of dry periods. The Tigris and Euphrates rivers played an important role in the development of civilization in the region. The presence of high mountains, valleys and swamps made it possible for a great variety of wild plants to survive, which served as valuable material for domestication. Legumes were among the first to be artificially selected along with wheat. A significant variety of climatic conditions has positively stimulated the evolution of plants, including adaptive changes. Therefore, wild ancestors of many species of agricultural plants are still found on these lands, which are valuable for breeding work. This is especially true for resistance to pathogens, pests, high temperatures and drought. Legumes, especially chickpea and lentils, just belong to the group of drought-resistant, they are grown, as a rule, where other crops do not give economically justified yields.

The soil and climatic conditions of Ukraine are quite favorable for the cultivation of this group of crops, some of them were cultivated in the past, then they were forgotten, although in this period they are quite promising. Therefore, in 1979, soybean breeding was launched at the Plant Breeding and Genetics Institute, then chickpea was added to it, in 2000 breeding work with pea was resumed, and in recent years the creation of lentil source material has begun. It is important to note that Ukraine has quite a large potential for increasing the production of marketable seeds of leguminous crops. This is due to such factors as the presence of highly fertile lands and varieties well adapted to zonal conditions, a well-established system for the production of high-quality seeds, trained specialists, a large assortment of soil and post-emergent herbicides and bacterial fertilizers, rich experience in obtaining high yields of this group of crops.

2 Material and Methods

The experimental farm of the Dachne of the Plant Breeding and Genetics Institute, in the crop rotation of which the experiments were carried out, is located on the territory of the southern part of the Black Sea lowland, in the steppe zone of the Odesa region. The terrain is represented by an almost perfect plain.

The soil is southern medium-humus heavy loamy chernozems on loess deposits. The thickness of the humus layer is 40–50 cm, the humus content is 3.5–4.5%. The reaction of the soil solution is neutral or slightly alkaline (pH of the salt extract 6.0–7.2).

Climatic conditions in the research area are moderately warm, formed to a greater extent under the influence of Atlantic and Mediterranean air masses. The average annual air temperature is +9.6 °C, the sum of effective temperatures is 3,300 °C. Winters are mild and short. The coldest month is January, with an average long-term air temperature of -2 °C. The spring is early; the transition of temperature through +5 °C falls on the second or third decade of March. Summers are hot and long. In summer, the soil loses moisture due to high temperatures and a decrease in relative humidity, sometimes up to 35–40%, which leads to frequent dry winds. The temperature regime of the region does not limit the development of leguminous crops, however, arid conditions, as a rule, are accompanied by high temperatures, which inhibit plant growth. The arid nature of the climate is caused not only by the lack of total precipitation (380–450 mm), but also by its uneven distribution during the growing season.

For more than 40 years of breeding work with soybean, among the studied samples of the world collection (>5,000 genotypes), sources and donors of indicators that determine the yield to the greatest extent have been identified. We found genotypes that better tolerate adverse environmental conditions (drought, low temperatures, extended daylight), as well as cultivars with an increased amount of protein in seeds and a slight variability of this trait over the years. The advanced breeding material for the creation of hybrid populations was attracted from M.I. Vavilov All-Russian Research Institute of Plant Production (VIR) and Guelph University (Canada), where the first author of this work was trained.

For chickpea breeding, the primary gene pool came from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, India, Patancheru), from where we obtained more than 2000 genotypes. A significant contribution to our chickpea breeding program was also made by collection varieties received from the National Center for Plant Genetic Resources of Ukraine (Kharkiv).

Breeding work with pea at the institute began in pre-war times, but at the end of the last century it was suspended. Taking into account the importance of pea for the agricultural sector of Ukraine, in 2000 it was renewed on a new genetic basis, in connection with the discovery of genes of the "leafless" type and short-stemmed. At present, we intensively use the genotypes of pea "chameleon" and "lupinoid" obtained at the All-Russian Research Institute of Leguminous and Groat Crops in hybridization.

The total amount of protein in the seeds was determined by the Kjeldahl method on the Kjeltec-Auto automatic device, fat – by Rushkovsky. Fractionation of soybean proteins was performed by the method of Davidson and others in the modification of the Laboratory of Biochemistry of our Institute, pea proteins – according to Osterman. The analysis of trypsin inhibitors was carried out by the casein method.

3 Results and Discussion

Taking into account the complex of positive signs, the sown areas and seed production of legumes in the world are constantly growing (Table 1). Their yield is also gradually increasing.

Table 1 Acreage and yield of leguminous crops in the world

Year	Sown area (Mha)	Yield ($t.ha^{-1}$)	Seed production (Mt)
1961	64.01	0.64	40.78
1971	63.51	0.67	42.67
1981	62,56	0.66	41.63
1991	70.73	0.79	56.17
2001	67.64	0.83	56.34
2011	79.63	0.88	70.32
2014	83.46	0.94	78.86
2016	89.71	0.98	87.83
2018	94.95	0.97	92.32
2019	89.06	0.99	88.38
2020	93.18	0.96	82.82

From the data, it can be seen that a significant increase in the production of this group of crops began only at the end of the last century and the beginning of the XXI century. In the 1970s–1980s they occupied about 63 million hectares (Mha) on our planet. In 2011 their area exceeded 79 Mha and the production for this period increased by almost 28 million tons (Mt). In the following decades, this trend continued, and only in 2019 there was

Table 2 Dynamics of sown areas of the main leguminous crops in the world in Mha

Crop	Year							
	1961	1970	1980	1990	2000	2010	2018	2020
Soybean	23.8	29.5	50.6	57.1	74.4	102.6	124.0	126.9
Common bean	22.8	23.3	25.5	26.5	23.9	30.2	36.2	34.8
Chickpea	11.8	10.2	9.6	9.9	10.1	12.0	16.2	14.8
Cowpea	2.4	5.6	3.5	5.6	7.6	11.6	14.3	15.0
Pea	7.6	7.8	7.0	8.7	6.0	6.6	7.4	7.2
Faba bean	5.4	4.8	3.7	2.8	2.5	2.6	2.8	2.7
Pigeonpea	2.7	3.0	3.0	4.2	4.3	4.8	5.4	6.1
Lentil	1.6	1.7	2.1	3.2	3.9	4.4	5.5	5.0
Vetch	2.2	1.7	0.9	1.3	0.9	0.5	0.3	0.3
Lupine	1.1	1.0	0.5	1.0	1.3	0.8	0.9	0.9

a certain decline in production, which is due to changes in the export market. Thus, during the XXI century (2001–2020), the sown area of leguminous crops increased by more than 25 Mha, and the production of seeds – by 26 Mt. Seed production in 2016–2020 doubled compared to 1981. In accordance with the program developed by FAO, the production of leguminous crops will develop at an accelerated pace until 2029. It should be noted that Table 1 does not take into account data on the cultivation of such a valuable high-protein crop as soybean. According to the complex of biological characteristics of plants and seeds, it belongs to the group of legumes. It is one of the most important crops in world agriculture, which ranks fourth in terms of crop area after wheat, corn and rice. The change in sown areas by years in the context of individual crops is shown in Table 2.

In the 21st century (2001–2020), cowpea and soybean had the highest growth area, followed by bean and chickpea. During this period, the yield of these crops also increased significantly. For example, in soybean it increased from 2.17 to 2.78 t.ha^{-1}, in common bean from 0.74 to 0.79 t.ha^{-1}, in pea from 1.79 to 2.04 t.ha^{-1}. If lentil yield in 2000 was 0.87 t.ha^{-1}, then in 2020 it increased to 1.30 t.ha^{-1}. But the level of yield does not always determine the rate of distribution of the crop. For example, in the last decade of the 20th century, the yield of cowpea per hectare did not exceed 600 kg.ha^{-1} in any year, although it ranks third in terms of the growth rate of areas among leguminous crops. This testifies to the decisive importance of local traditions in obtaining certain products.

Most of the crops listed in Table 2 are used in the food industry or used for cooking without special preparation. Soybean and pea are also known as important protein additives for the preparation of compound feed. Vetch and lupine seeds are fully used for feed needs. Thus, the analysis of Table 2 convincingly shows a significant increase in the use of leguminous crops to improve the nutrition of the population of our planet.

The value of these crops is shown in Table 3.

It should be noted that Ukraine is also in the trend of a significant increase in the production of certain leguminous crops to improve the nutrition of the population. First of all, this applies to soybean. If in 2000 the soybean area was only 60.6 thousand hectares, in 2010 it had already exceeded one Mha, and in 2016 it reached almost 2 Mha. The yield during this period increased from 1.06 t.ha^{-1} to 2.30 t.ha^{-1}. In recent years, soybean in our country has been cultivated on an area of about 2 Mha with a yield of 2.0–2.5 t.ha^{-1}.

Of course, on a global scale, soybean is the main producer of high-quality protein for livestock, poultry and fish farming. But significant amounts of it are used for food purposes (about 10%). In China, Japan, and Korea, a number of analogues of dairy products are produced – soy milk and fermented milk products, and cheese tofu. In the countries of the East, food products obtained as a result of fermentation such as soy sauce, sufu, miso, tempeh, etc. are intensively used. For their preparation, high-quality seeds are needed, which are distinguished by their size, increased level of protein, and the absence of a pronounced hilum on the seed. The use of these products in Eastern countries has a thousand-year history.

Quite often, deodorized soy flour with a significant amount of carbohydrates is used for the manufacture of meat products. The protein content in it is 47–56%, depending on the level of degreasing.

The modern technology of processing soybean into food products, which is intensively developing in the United States and European countries, consists in the extraction

Table 3 Nutritional value of leguminous seeds

Name	Scientific name	Calorie		Content (%)	
		kcal	kJ	protein	fat
Bambara groundnut	*Vigna subterranea*	376	1,590	20.1	5.90
Broad bean	*Vicia faba*	300	1,260	26.1	1.80
Cowpea	*Vigna unguiculata*	335	1,418	21.1	1.20
Lentil	*Lens culinaris*	297	1,240	25.4	1.80
Pigeon pea	*Cajanus cajan*	301	1,260	18.4	1.50
Adzuki bean	*Vigna angularis*	329	1,377	19.9	0.53
Pinto bean	*Phaseolus vulgaris*	347	1,452	21.4	1.23
Black bean	*Phaseolus vulgaris*	324	1,354	21.3	1.20
White bean	*Phaseolus vulgaris*	337	1,411	23.3	1.50
Mung bean	*Vigna radiata*	347	1,452	23.9	1.15
Red bean	*Phaseolus vulgaris*	337	1,408	22.5	1.06
Chickpea	*Cicer arietinum*	355	1,484	21.2	5.40
Kabuli chickpea	*Cicer arietinum*	372	1,565	22.0	6.05
Desi chickpea	*Cicer arietinum*	343	1,441	21.0	5.10
Black gram	*Vigna mungo*	341	1,427	25.2	1.64
Lupine	*Lupinus albus*	371	1,554	36.2	9.74
Cannellini bean	*Phaseolus vulgaris*	279	1,166	23.4	1.60
Borlotti bean	*Phaseolus vulgaris*	291	1,216	20.2	2.00
Pea	*Pisum sativum*	308	1,294	18.4	1.40

Source: Pulses: Nutritious Seeds for a Sustainable Future, FAO, 2016

of oil from soybean seeds and the production of meal, which is fat-free flakes, which are the basis for further processing into higher quality ingredients. They are used to make the simplest type of food products – soy flour and groats. To do this, the fat-free flakes are simply ground and sifted. The protein content in them is 56–59% (for absolutely dry matter). Soy flour and groats are used in baking bread, making cookies, pies, cakes, and other bakery and confectionery products. An increased amount of protein is released by soy concentrates and isolates. In the former, the protein content is 65–72%, in the latter – 90–92%. They are obtained using a special technology by precipitating protein components with acid. These foods are among the most concentrated sources of plant-based protein in the world. They are used to make cutlets, sausages, analogues of fish fillets, shrimps, etc. A significant amount of soy isolate is used to make dairy products. In recent years, preference has been given to textured protein products with a fibrous structure, which, after hydration, resemble pork, beef, poultry and fish in appearance and taste. Original textured products are stored for a long time, easily hydrolyzed, they are produced in the form of pieces of various shapes and sizes (goulash, meatballs, cutlets, beef stroganoff, granules).

The quality of raw materials, i.e. seeds, is important for the production of quality food ingredients from soybean. The main indicator here is the protein content, which determines the quality of the final product. Therefore, in recent years, the price of individual batches of seeds on the world market significantly depends on this indicator. Soybean with a protein content of about 40% non-transgenic origin is especially valued.

Soybean grown in Ukraine is fully suitable for use for food purposes. Today, it even has a significant advantage, since national varieties are created by traditional breeding methods, while American, Brazilian and Argentine soybean are almost entirely transgenic. Table 4 shows the protein content of varieties grown in the Odessa region.

In accordance with the breeding program, the development of high-protein varieties at the institute continues. To this end, a cycle of new crosses is carried out, and new collection genotypes of foreign origin are involved in hybridization, especially from China and Japan. As an example, we present the protein content of new lines of competitive advanced testing, which at the same time exceeded the yield of the standard variety (Table 5).

Tables 4 and 5 show that seeds of domestic soybean varieties meet high international standards, they contain an average of about 40% of protein of non-transgenic origin, and it is possible to produce "organic" products. In addition, the soybean varieties we created differ in the rate of swelling during water-heat treatment, the activity of trypsin inhibitor, lipoxygenase and urease.

Storage soybean proteins, which are concentrated in the cotyledons, belong to the fraction of globulins, which, depending on the conditions of the year, ranges from 67–77%. In further studies, it was found that globulins include two fractions that are characterized by sedimentation constants 7S and 11S. They have a rather complex structure of separate subunits, each of which consists of an acidic and a basic protein molecule with different molecular weights, which are linked together by disulfide bonds. It is these characteristics that determine the quality of food products obtained from soybean proteins (Adamovskaya et al., 2003). Electrophoresis of isolated globulin fractions revealed significant fluctuations depending on the variety. No relationship was found between the total protein content in soybean seeds and a certain fraction (Adamovskaya et al., 2014). This conclusion indicates the possibility of improving the balance of soybean protein by breeding.

Summarizing the above, we can conclude that the availability of high-quality raw materials serves as a good basis for the production of valuable food products from soybean seeds in Ukraine. In recent decades, this process has begun, albeit at a slow pace. In the beginning, the main attention was paid to analogues of dairy products. Many types of "dairy cows" were installed, which were easy to maintain and cheap. This boom was especially manifested in the 90s of the last century. Then there were fewer of them, but a significant number of them have been functioning for a long time. There are few isolates and concentrates produced in the country, although a certain amount is supplied from abroad. In the future, the raw materials for the production of soybean protein products will be constantly improved, which will significantly improve the economic indicators of its production.

Table 4 Protein content in seeds of soybean varieties created at the Plant Breeding and Genetics Institute, by years

Variety	Protein content (%)				
	2016	2017	2018	2019	average
Siaivo, standard	43.2	41.3	37.0	34.1	38.9
Orfei	43.6	42.9	42.0	36.3	41.2
Antares	44.7	41.3	40.5	36.9	40.8
Symfoniya	42.6	40.8	39.3	39.6	40.6
Evridika	44.5	40.8	40.8	33.8	40.0
Aryadna	43.7	40.2	39.2	36.5	39.9
Altayir	42.0	41.3	40.2	35.4	39.7
Feniks	43.2	40.6	40.3	33.6	39.4
Danko	42.3	39.2	40.0	35.9	39.4
Farvater	41.6	37.9	39.3	33.4	38.0
Vasylkivska	40.6	35.9	38.6	35.0	37.5
$LSD_{0.05}$					1.9

Table 5 Protein content in seeds of high-yielding advanced soybean lines

Line number	Pedigree	Protein content (%)					
		2015	2016	2017	2018	2019	average
	Siaivo, standard	41.9	43.2	42.1	38.7	34.2	40.0
31008/19	Hybrid 905/Senhae No 20	42.3	43.1	43.4	43.5	38.3	42.1
31000/19	7293/98	42.1	45.2	42.3	43.4	37.2	42.0
31020/19	Simpson/K-4937	41.1	43.1	43.2	42.1	39.5	41.8
30950/19	Volgogradka/Montreal	40.9	45.2	43.0	41.5	36.9	41.5
$LSD_{0.05}$							1.6

It should be noted that in parallel with the production of soybean protein ingredients, a huge amount of edible soybean oil is produced in the world, which stands out for its high nutritional quality. In terms of production in the world, it ranks second among edible vegetable oils after palm oil (Table 6).

According to forecasts vegetable oil production will continue to grow and its volume will reach 214.8 Mt. At the same time, the amount of palm oil will reach 76.5, soybean – 61.7, sunflower – 21.8, rapeseed – 27.4 Mt.

Soybean oil stands out for its excellent nutritional qualities, since it contains 62% polyunsaturated fatty acids (linoleic and linolenic), which are not synthesized in living organisms and must necessarily come with food. It contains many vitamins, especially vitamin E, tocopherols, which are characterized by antioxidant action.

An important effect on human health is exerted by such components of soybean seeds as isoflavones (genistin, genistein, daidzin, daidzein), which are characterized by hormonal action. Depending on their abundance, they have a positive effect on the fertility of humans and animals, although in excess they can lead to reproductive imbalances (Chavarro et al., 2008; Bennetts et al., 2008; Messina, 2010; Hamilton-Reeves et al., 2010).

Since the bulk of the grown soybean is used for processing into feed additives and for the production of edible oil, the main indicators of varieties used for this purpose are the content of protein and oil in the seeds. The ever-increasing use of soybean in the food industry has led to the separation of a specific direction of breeding – the creation of varieties for food use. Its development occurs in several ways. The first of these is the creation of varieties with large beans that are sweet in taste due to the increased amount of carbohydrates in the seeds and a weakened herbal flavor (Carrao-Panizzi, 1989; Orf, 1989; Vello, 1992). Edible varieties of soybean of the second type should be distinguished by the underestimated activity of antinutrient factors, especially the trypsin inhibitors Kunitz and Baumann-Birk (Orf, 1989). In addition, to obtain sprouts and fermented natto product, cultivars of soybean with small seeds are required (weight of 1,000 seeds is less than 100 g).

It is important to note that, on average, every Japanese person consumes 27.8 mg of isoflavones daily with food (Nakamura et al., 2000). It is believed that such significant amounts of these biologically active substances have a preventive effect on breast cancer in women and on cancer in men (Chang et al., 2008; Yan, & Spitznagel, 2009; Andres et al., 2011; Global Cancer Statistics, 2002). In connection with the therapeutic and prophylactic properties of these products, it is argued that in the future the nature of human nutrition will change significantly, and preference will be given to ingredients with significant biological activity, which have a significant functional effect on one or more physiological functions of the human body. Among these biologically active substances, a significant niche is occupied by products of seed processing of leguminous crops. In recent years, a new term "alternative protein" has been proposed for use, which refers to all types of non-animal proteins. Today, it occupies about 4% of the global amount of proteins, although its annual increase is 2–3 times greater compared to meat and chicken (Joseph et al., 2020).

A very good source for obtaining high-quality food components is also such leguminous crops as pea, chickpea, lentil, common bean, for which the soil and climatic conditions of Ukraine are quite suitable.

In Ukraine, there are all the necessary components for the expansion of pea. There are 47 varieties in the State

Table 6 Global production of vegetable oils in the world, Mt

Vegetable oil	Oil production (Mt)			
	2012	2014	2016	2018
Palm	52.6	61.8	65.3	73.6
Soybean	42.7	49.3	53.7	57.2
Rapeseed	24.0	27.5	28.2	28.6
Sunflower	14.3	15.0	18.2	20.4
Palm (kernel)	6.2	7.3	7.6	8.2
Peanut	5.3	5.4	6.0	6.1
Cotton	5.2	5.1	4.4	4.1
Coconut	3.4	3.4	3.4	4.1
Olive	3.5	2.4	2.5	2.0
Total	157.2	177.2	189.2	204.4

Register of Plants of Ukraine, 22 of which were bred by research institutions of our country. The results of variety testing by research stations and collective farms indicate that under optimal growing conditions, the yield of new varieties reaches 5.0 t.ha^{-1}. They are characterized by high resistance to lodging and diseases, and are suitable for direct harvesting. The greatest contribution to the creation of varieties of this type was made by the Yuriev Institute of Plant Production, Institute of Bioenergy Crops and Sugar Beets of the National Academy of Agrarian Sciences of Ukraine, Plant Breeding and Genetics Institute – National Center for Seed and Cultivar Investigation. Since significant areas of culture are located in the steppe zone, we have bred drought-resistant varieties for it, the height of which is 80–85 cm. A number of varieties resistant to lodging and diseases were created at the Yuriev Institute of Plant Production. In recent years, a new innovative direction of pea cultivation has been launched – winter sowing (Sichkar, Solomonov, 2019; Sichkar et al., 2021). Our 7-year research in the central zone of the Odessa region indicates a significant prospect in increasing crops of this kind. A characteristic feature of the last decade is the significant instability of yields over the years of almost all crops, including pea. Thus, over the past 6 years, the average pea yield in our country has ranged from 1.86 to 3.16 t.ha^{-1}. Such variability is due to the insufficient amount of moisture in the soil and the air temperature during the growing season. The development of new varieties with increased adaptability to insufficient moisture in the soil and high air temperatures and the introduction of moisture-saving technologies, including sowing in autumn, will significantly reduce the variability of yield over the years and stabilize the production of pea in our country. The increase of its areas will complement the number of the best predecessors for the main crop of Ukraine – winter wheat.

The production of pea in Ukraine in the current century is shown in Table 7.

At the end of the last century, pea in our country amounted to almost 1.5 Mha, and the production was at the level of 3.5 Mt. Today, there is an extremely important task to revive the area under pea to the level of the 1980s–1990s. It should be noted that the main exporters of wheat in the world – the USA, Canada, Russia – grow this crop on large areas. It is important to note that its yield in our fields is at the level of the above-mentioned countries. For example, the average yield of pea in Ukraine for 2017–2020 was 2.19 t.ha^{-1}, while in the USA – 2.15, Canada – 2.58, Russia – 2.07 t.ha^{-1}. In the USA, the substitution of fallow for pea has increased dramatically over the past decade in an arid region, the so-called wheat belt (Great Plains), with precipitation at the level of 320–400 mm. These are the states of Kansas, Oklahoma, Nebraska, Colorado and others.

American scientists in long-term studies have clearly proven that the yield of wheat after pea increases by 12% compared to other predecessors, including soybean. This combination of crops gives a synergistic effect, which arises due to more efficient use of moisture, improved microbiological biota of the soil and its waste products that stimulate plant growth. It is important to note that this reaction manifests itself in an intensified form under the influence of drought. Thus, the link of crop rotation "pea – wheat" can serve as the basis for effective crop rotation in arid regions.

The main value of pea seeds lies in the high content of high-quality protein, the amount of which, depending on the genotype, varies between 22–25%. For food purposes, it is obtained by extraction, similar to soybean. The isolate, which is processed in this way, contains approximately 90–95% protein, is characterized by excellent emulsification and dispersion abilities, therefore

Table 7 Sown areas, yield and production of pea in Ukraine

Year	Sown area (thousand ha)	Yield (t.ha^{-1})	Production (thousand tons)
1987	1,437.00	2.41	3,471.70
2000	258.20	1.75	499.40
2005	311.10	1.98	616.00
2010	278.50	1.62	452.40
2015	182.20	2.14	390.00
2016	238.00	3.16	752.10
2017	405.00	2.67	1,081.40
2018	431.50	1.86	802.60
2019	257.00	2.27	583.40
2020	235.00	2.17	509.90
2021	236.30	2.44	576.20

it is an important ingredient for the food industry. On its basis, not only meat analogues are prepared, but also products such as snacks, crackers, pizzas, various types of kasha, pasta, biscuits. At the well-known French plant for the production of pea protein "Roquette", isolates with high functional and nutritional qualities are produced. At the second largest producer of pea protein in Europe, the Belgian plant "Cosucta", the process is organized in such a way that protein isolate, starch and dietary fiber are produced from the seeds at the same time. Large factories of this type operate in China, Canada and England (Khrulev et al., 2016).

Another important feature of pea seeds is a significant amount of starch in them, which is easily absorbed by the human body and has a great energy value. This component consists of amylose, whose macromolecules have a linear structure, and amylopectin, which is characterized by branched molecules. It is important to note that pea starch is secreted by an increased level of amylose (up to 75%). Despite the similar chemical composition, these starch components differ in spatial structure and their separation is based on unequal dissolution and precipitation.

At present, a waste-free technology for separating starch from commercial pea seeds has been developed for the use of the obtained ingredients in the food industry in order to improve their biological value (Shelepina, 2014). The isolated starch is used in the production of pasta and bakery products. The fraction of the embryonic materials, which is formed during processing, is characterized by high protein content and the content of a number of biologically active compounds, is used as an admixture in the manufacture of bread and a number of confectionery products. The quality of bakery and pasta products, in the manufacture of which pea starch was used, fully complies with the normative indicators (Shelepina, 2014). It is important to note that the embryonic products, in addition to a high level of protein, is distinguished by an excellent lipid complex, which is formed from a significant amount of such unsaturated fatty acids as oleic and linoleic, which are not synthesized in the human body and must be supplied with food.

The amylose content of starch has a significant effect on water absorption and starch gelatinization temperature. With a reduced amylose content, less water is absorbed and the gelatinization process takes place at a lower temperature compared to typical starch. High-amylous starch is a valuable raw material for the chemical industry, especially in the production of biodegradable plastics, including packaging, and films used in the food industry and medicine.

Due to the high value of high-amylose starch, specialized selection of pea began in order to create varieties with a changed starch structure, as is already the case in wheat and corn. Such work is intensively carried out at the Yuriev Institute of Plant Production (Kharkiv) and at the All-Russian Research Institute of Leguminous and Groat Crops (Russian Federation, Orel).

Pea seeds are used as raw materials in the food and feed industries. In addition, it is well known in the world as an important vegetable crop. Most of the canned food is made from it in China and India. Significant quantities of green pea are frozen and in this form are used as a culinary by-product.

Significant positive changes are observed in general on our planet with crops such as chickpea and lentil. It is believed that this is a new, more progressive stage in the development of nutrition, since their seeds are distinguished by both a rich set of functional macronutrients (essential amino acids, polyunsaturated fatty acids, phospholipids, dietary fibers) and micronutrients (minerals, vitamins, flavonoids, etc.). In addition, their seeds, as raw materials for the manufacture of food, are characterized by a much better set of technological features. The characterization of lentils as a crop of nutritional value was provided by us earlier (Sichkar et al., 2020). It should be noted that chickpea is not inferior to lentil in terms of use for food. If in 2018–2020 lentil areas reached 5.3 Mha, while in chickpea they amounted to 15.4 Mha, that is, they were almost three times larger. Both of these crops were distinguished by an intensive increase in sown areas and production in the XXI century, although in 2019–2020 there was a slight drop in their production, which was due to a significant increase in India's import duties, which led to a sharp drop in prices on the world market. Nowadays, high prices for seeds of these crops have been resumed, and a new trend of growth in their production begins in 2021.

It is important to note that both lentil and chickpea belong to the group of drought-tolerant crops, which is of particular importance in the context of global warming.

For Ukraine, the experience of Canada, where lentil began to be grown at the end of the last century in the steppe zone (provinces of Saskatchewan and Alberta), is very valuable. In 1975, only 400 hectares were sown with it for the first time, and then the area began to grow rapidly and this country in a short period of time became the main producer and exporter of lentil in the world. The sown area has reached 1.7 Mha, and the yield level in recent years has been 1.4–1.6 $t.ha^{-1}$. Thus, due to this crop and pea, which are also sown with the same area,

Table 8 Characteristics of chickpea varieties in the conditions of the Southern Steppe of Ukraine

Cultivar	Seed yield (t.ha^{-1})		Duration of vegetation period (days)	Height of attachment of lower beans, cm	Weight of 1,000 seeds (g)	Protein content (%)
	average	maximum				
Rosanna	1.56	2.83	92.00	22.00	320.00	27.00
Aleksandryt	1.78	2.91	88.00	18.00	275.00	26.50
Pamiat'	1.54	2.71	91.00	21.00	315.00	27.10
Antei	1.48	2.56	88.00	20.00	390.00	28.30
Pegas	1.59	2.78	85.00	18.00	265.00	27.50
Triumf	1.55	2.79	93.00	21.00	405.00	28.70
Budjak	1.60	2.61	91.00	22.00	412.00	27.90
Odysei	1.61	2.46	91.00	22.00	415.00	28.50
Skarb	1.65	2.58	94.00	22.00	420.00	26.90
LSD.05	0.16	–	–	1.06	24.88	1.52

Canadian farmers have an excellent precursor for wheat, the grain quality of which is known all over the world.

Chickpea is distinguished by its typically xerophytic plant structure – a small habitus of the bush, small leaves, and high osmotic pressure of cell sap. Its leaves and beans are densely covered with hairs that secrete a lot of oxalic acid, which repels many pests. Chickpea is quite common in world agriculture and its acreage in 2018 reached 17.8 Mha, and the production amounted to 17.2 Mt. It is distinguished by a high level of attractiveness – it does not lie down, the beans do not fall off or crack, they are tied at a height of 20–25 cm from the soil surface, which contributes to high-quality harvesting.

The Plant Breeding and Genetics Institute has created 12 varieties of this crop, which are included in the state register of Ukraine. An important achievement is the development of large-seeded varieties, which are highly valued in the world market. Their main indicators are shown in Table 8. In addition, chickpea varieties of our breeding belong to the group of drought-resistant. And this trait is extremely important for stable seed production, since it is known that on our planet as a whole, the average drop in chickpea yield from drought is 45–50% (Ahmad et al., 2005; Thudi et al., 2014). To date, chickpea seed production tends to be grown due to the constant growth of the population of our planet (Henchion et al., 2017; Chaturvedi et al., 2018).

Under the conditions of our country, the varieties Rosanna, Triumf and Pamiat' are widespread.

As a result of many years of study of chickpea collections, we have identified sources of increased seed productivity, large-seeded, high protein content, tolerance against pathogens, and improved technological qualities. Individual genotypes have been identified, in which several economically valuable traits have been improved. It is shown that when the traits of samples of different ecological and geographical origin are combined in one genotype, there is a high probability of obtaining valuable recombinant lines through the accumulation of positively acting adaptive genes. A particularly wide diverse of source material is necessary to prevent outbreaks of diseases and the intensive spread of pests, the danger from which increases significantly with the uniformity of the gene pool.

We believe that chickpea should be cultivated not for super-profits, but for justified crop rotations, especially in the steppe zone. Due to the aridization of the climate, lentil and chickpea will grow steadily in the future.

Our country belongs to those zones in which global warming is manifested quite actively. The average annual temperature has increased by 1.6–1.7 degrees Celsius over the past few years. Approximately every year, the warm period increases, and the winter period decreases.

Further growth in the production of leguminous seeds will contribute to ensuring food security and adequate nutrition of the population of our planet, improving human health, combating climate change, preserving biodiversity, maintaining soil fertility and improving the environment. On a global scale, legume seeds and cereals and rice complement each other quite well.

4 Conclusions

The balance of protein resources on our planet is negative, so there is a strategic need for a sharp increase in the production of leguminous crops seeds. The soil and climatic conditions of Ukraine fully meet the needs of this group of crops. Domestic varieties of soybean, pea and chickpea meet the needs of producers, they are technological, relatively resistant to insufficient moisture,

the seeds contain a high level of ingredients valuable for nutrition. Further breeding work with leguminous crops should be aimed at improving the complex of adaptive traits and improving the chemical composition of seeds, especially essential amino acids, critical microelements, and biologically active compounds.

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