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Article

A comprehensive analysis of soybean breeding in Russia: Insights into soybean varietal diversity

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Abstract: This study analyses the dynamic development of soybean (*Glycine max* (L.) Merr.) breeding in Russia, particularly examining its historical development, status, and future predictions. With the global demand for vegetable protein rising, understanding Russia's potential contribution becomes crucial. This research provides valuable insights, offering precise data that may be unfamiliar to international researchers and the private sector. The authors trace the history of soybean selection in Russia, emphasizing its expansion from the Far East to other regions in Russia. The expansion is primarily attributed to the pioneering work of Soviet breeder V. A. Zolotnitsky and the development of the soybean variety in the Amur region in the 1930s. The study highlights the main areas of soybean variety originators, with approximately 40% of foreign varieties registered. The Krasnodar and Amur regions emerge as critical areas for breeding soybean varieties. In Russia, the highest yield potential of soybeans is in the Central Federal District. At the same time, the varieties registered in the Volga Federal District have higher oil content, and the Far Eastern Federal District has high protein content in the registered soybean varieties. The research outlines the state's pivotal role in supporting soybean breeding and fostering a competitive market with foreign breeders. The study forecasts future soybean breeding development and the main factors that can influence the industry.

Keywords: active temperatures; soybean; mapping; varietal diversity; Russia; sustainability

1. Introduction

The diversity of soybean varieties is one of the fundamentals of crop production technology, and it plays a significant role in determining crucial aspects of soybean production, including yield levels and product quality (Lambirth et al., 2015; Mangena, 2021; Novikova et al., 2020; Pagano and Miransari, 2016). Within the realm of agricultural production, seed breeding represents a specialized discipline tasked with propagating seeds derived from established varieties and hybrids (Lambirth et al., 2015; Mangena, 2021). This propagation is conducted in quantities suitable for large-scale production, all the while aiming to preserve and ideally enhance their inherent planting characteristics and yield (Demianova-Roy et al., 2022; Novikova et al., 2020; Zotikov and Vilyunov, 2021).

Soybeans are known for their relatively high yield potential, especially when grown in suitable climatic conditions with proper agronomic practices. When compared to other staple crops such as wheat, barley, and corn, soybeans can often produce comparable or higher yields per hectare. Soybeans benefit from strong global market demand, driven by their versatile uses in food products, animal feed, and industrial applications (Tiwari, 2017). The demand for soybeans has been steadily increasing, particularly in markets like China, which is the largest importer of soybeans (Sinegovskii et al., 2021; Wang et al., 2023). Soybeans generally offer more price stability and higher market prices compared to many other crops, providing farmers with a reliable income source (Adi Sofyan Ansori and Aji Suseno, 2018).

Soybeans require a considerable amount of heat and light, and have been able to expand their geographical range thanks to the development of new varieties that exhibit greater tolerance to diverse natural conditions (Gong et al., 2022; Volkova and Smolyaninova, 2023). As a result, soybean cultivation is now prevalent in more than 95 countries, including regions with northern latitudes (Jia et al., 2014), which was previously thought to be impossible due to adverse climatic conditions (Demianova-Roy et al., 2022; Yerzhebayeva et al., 2023).

Notably, the Eastern region of Russia has emerged as a prominent center for soybean cultivation, defying its location far to the north of the traditional soybean belt (Tikhonchuk et al., 2016). This northern expansion can be credited to the pioneering endeavours of V. A. Zolotnitsky, a Soviet breeder who, in 1930, harnessed selective breeding techniques to isolate an exceptional plant from the native population of the Manchurian subspecies of yellow soybean (Shchegorets et al., 2020; Sinegovskaia, 2021). This breakthrough led to the creation of the Amur region variety, subsequently designated as "Amurskaya 41" in 1934. The "Amurskaya 41" variety boasts significant advantages in terms of early maturation, high yields, and adaptability (Shchegorets et al., 2020; Tikhonchuk et al., 2016).

As previously mentioned, this variety's characteristics have significantly contributed to the expansion of soybean cultivation in northern regions and the establishment of the Far Eastern soybean breeding branch. Given Russia's predominantly northern latitude, the successful cultivation of soybeans hinges on the use of early-maturing, high-yielding varieties (Shchegorets et al., 2020; Sinegovskii et al., 2018; Tikhonchuk et al., 2016).

According to a recent study, Karges et al. (2022) propose expanding soybean cultivation into the northern territories of Europe, a region that shares similar climatic constraints with northern Russia. This expansion could not only increase soybean production but also offer new economic opportunities for farmers, suggesting a parallel strategy for Russian agriculture. Research on the expansion of soybean cultivation in northern regions of China is also being conducted (Zheng et al., 2009). Importantly, the northern territories of China border the southern territories of the Russian Far East, creating a region with shared climatic and soil characteristics. This geographical proximity means that successful soybean cultivation practices and varieties developed in northern China can be highly relevant and applicable to the Russian Far East. Prior studies on the yield of soybeans, with regard to changes in climate (Qian et al., 2016; Qiao et al., 2023; Shi et al., 2013; Zheng et al., 2009), maturity periods (Fadeev, 2023; Hodges and French, 1985; Katyshev et al., 2021), and cultivation conditions have been conducted.

Nowadays, the Federal Scientific Centre All-Russian Scientific Research Institute of Soybeans (FSCARSRIS) in the Amur region supports soybean production in the Russian Federation. This specialized institute is dedicated to the development of new soybean varieties and provides scientific assistance to soybean farmers (Sinegovskaia et al., 2016; Sinegovskii et al., 2018). In fact, the institute has successfully developed high-yielding soybean varieties with varying vegetation periods and yield potentials ranging from 2.0 to 3.5 t/ha. These varieties also exhibit favorable protein content ranging from 34.2% to 44.3% and 14.6% to 23.2% oil content. Over 85% of the soybean crops in the Amur region are grown from selection varieties developed by ARSRIS, encompassing an area of 600,000 hectares. Popular varieties include "Sonata," "Harmony," "Dauria," Lydia," and "Lazurnaya," and new varieties are currently being introduced. Overall, the efforts of the Institute have contributed significantly to the growth of soybean production in Russia (Sinegovskaia et al., 2016; Sinegovskii, 2020; Sinegovskii et al., 2018, 2021; Volkova and Smolyaninova, 2023).

The introduction of the 1993 Law of the Russian Federation "On Breeding Achievements" marked a transformative shift in the development of various resources (WTO, 2016). Instead of being categorized by zones, varieties are now included in the State Register of Breeding Achievements based on their performance in state variety trials. This inclusion grants them the privilege to be multiplied, imported, and sold as seeds within the corresponding regions of Russia's constituent entities (Ministry of Agriculture of Russia, 2022; Sinegovskaia, 2021). At present, more than 30 scientific research institutions in Russia are actively involved in soybean breeding efforts. These collaborative endeavors have culminated in the creation of the State Register of Breeding Achievements, which encompasses an array of 280 soybean varieties (Ministry of Agriculture of Russia, 2022; Sinegovskaia, 2021).

Soybeans have played a pivotal role in Russian agriculture, with extensive research over the years contributing to a deep understanding of their physiology and genetics. This has led to the development of early-maturing soybean varieties capable of thriving in regions with limited thermal resources, such as Russia, thereby enhancing productivity and resilience to major stressors (Sinegovskii, 2024). Efforts to combat common soybean diseases emphasize early planting, optimal seeding rates, adherence to recommended seeding densities (Boiarskii et al., 2019), harvest moisture content (Popov and Bumbar, 2023), precise agronomic practices (Vaitekhovich et al., 2022; Zakharova and Nemykin, 2022), utilization of disease-resistant varieties (Butovets et al., 2022), seed treatment, and chemical and biological fungicides (Mikhailova et al., 2020). Additionally, proper crop rotation practices and the destruction of plant residues are essential for disease management (Rezvichkiy et al., 2021).

In soybean production, it is important to take into account their composition, specifically emphasizing the significant role of protein. The production of soy protein concentrates involves extrusion cooking of dough and protein extraction from soybeans, with hydrolysates obtained through acid hydrolysis. However, the application of soy protein concentrates remains underexplored in Russia, particularly in livestock feed and various food sectors. Nevertheless, there is a growing global interest in using soy protein concentrates in sports, functional, and healthy diets (Bychkova and Borisova, 2021). Although soybean cultivation in Russia accounts for only about 2% of the global acreage and 1% of production, recent years have seen increased attention to this crop with the help of government support. Most of Russia's soybean harvest is directed toward oil mills for oil, phosphatides, meal, and cake production, with a significant portion exported to China (Dorohov et al., 2019).

Despite the potential for soybean production expansion in Russia, progress has been slower than domestic demand requires. Challenges such as outdated agricultural machinery, labor shortages, insufficient research funding, and inadequate technological advancements hinder the industry's growth. Adopting competitive foreign and domestic seed varieties and implementing scientifically sound agronomic practices are crucial for realizing soybean production potential (Zubareva, 2020). Efficient soybean seed separation into quality fractions involves using appropriate harvesting equipment, with improvements in combine harvester designs aimed at enhancing seed quality collection. Although currently a net importer of soybeans, Russia possesses significant potential to increase export volumes. However, this potential is constrained by challenges such as limited access to credit, underdeveloped market infrastructure, adverse climatic conditions, and the dominance of low-value exports (Sinegovskii et al., 2021).

The study aims to explore the role played by variety in soybean crop production technology, with a special emphasis on its influence on yield, protein, and oil levels. The study provides a comprehensive analysis of the soybean breeding state in Russia, involving a range of methodologies. Firstly, the study gathered and analysed open data on registered soybean varieties to identify the most prevalent cultivars across the country. Secondly, the study mapped soybean originators by location and divided them into two crucial periods before and after 2010 to discern the trends in soybean cultivation over time. Thirdly, the study characterized the given maturity groups to assess the adaptability of soybean varieties to different latitudes. Fourthly, the study overviewed soybean protein and oil content to determine the nutritional value of different cultivars. Lastly, the study projected the future of soybean breeding, highlighting the potential for further expansion and innovation. The study illustrated how diverse soybean varieties have facilitated the expansion of soybean farming in previously unviable northern latitudes, overcoming conventional climatic limitations.

2. Materials and methods

This research study was conducted with a comprehensive approach, utilizing a multifaceted array of research methods to explore and examine the soybean industry in Russia. The study employed various research methodologies such as economic-statistical, economic-mathematical, monographic, computational, and constructive research methods to provide a thorough understanding of the soybean industry. The research data was primarily sourced from official government reports of Russia (open data), which offered a valuable repository of statistical information. The study focused on gaining insights into the region's agricultural landscape through a detailed data analysis.

To identify the locations of the originators, we utilized QGIS, a free and open-source software (QGIS, 2022). Our first step was to obtain the shape file of Russian regions from a free source, which we found at https://gis-lab.info. Next, we compiled a database of all the originators and included parameters of region names that were associated with the region names key in the shape file. To present the originators' location and numbers, we merged the two files and generated a CSV file that provides a detailed overview of the originators' location and associated numbers.

The study utilized QGIS software (version 3.20.1) to conduct spatial interpolation of the observed data, which included georeferenced measurements of SAT above 10.1 C. The raw data were first imported into QGIS, where they were transformed into a point layer representing each data location's geographic coordinates.

The authors employed an interpolated irregular network (TIN) approach. This technique constructs a mesh of triangles linking each set of three nearest points in the dataset. Within each triangle, the surface is estimated using linear interpolation based on the vertex values, calculated as follows:

$$v(p) = w1 \times v1 + w2 \times v2 + w3 \times v3 \quad (1)$$

where, $v1$, $v2$ and $v3$ are the observed values at the triangle's vertices, and $w1$, $w2$, and $w3$ represent the barycentric coordinates, which depend on the position of point p relative to the vertices. This method effectively captures the variability of the surface, accommodating local topological variations within the dataset.

Upon generating the interpolated surface, the raster output was styled using a sequential color ramp to visually differentiate between the range of values present in the data. Finally, the interpolation map was exported from QGIS as a high-resolution image.

The statistical analysis of data and graphical representations was conducted using the R (version 4.3.2) programming software, which is widely recognized for its statistical computing capabilities (R Core Team, 2023). The ggplot2 add-on package was employed to produce and visualize the graphs.

To provide a broader perspective on global soybean trends, official international statistics databases were consulted, and a comparative analysis was conducted to assess how Russian regions fit into the larger soybean landscape. The analysis was underpinned by an exhaustive examination of various documents, including government regulations and programs related to the agricultural sector. These documents provided critical contextual information and policy insights that informed the research. Overall, the study provides a comprehensive and detailed overview of the soybean industry in Russia and lays the groundwork for future research in this field.

3. Results

3.1. Soybean production indicators across countries

Soybean cultivation is widespread, and major producing countries include Brazil, the United States, Argentina, China, and Canada (Qiao et al., 2023; Wang et al., 2023). These countries collectively account for most of the world's soybean production, with each country having unique cultivation practices and varieties. Comparing soybean varieties from different countries provides valuable insights into the global landscape of soybean cultivation. To provide a comprehensive analysis of soybean variety diversity in Russia, it is important to understand world tendencies. Russia, with its vast agricultural landscapes and diverse climatic conditions, offers a unique perspective on soybean cultivation practices and variety development.

As shown in **Figure 1**, Brazil and the United States are major global players in soybean production, known for both high yields and extensive cultivation. They have consistently been among the world's largest soybean producers. The USA consistently achieves high productivity per unit area with advanced agricultural technologies and favorable climatic conditions (Azam et al., 2021). Major soybean-producing states include Iowa, Illinois, and Minnesota. The USA exports a significant portion of its soybeans, contributing to its role as a major global supplier. Brazil is one of the leading soybean producers globally, known for its expansive agricultural land. Major soybean-producing regions in Brazil include Mato Grosso, Paraná, and Rio Grande do Sul. China is the world's largest importer of soybeans, relying heavily on imports to meet domestic demand. Despite being a major consumer, China does not produce enough soybeans domestically to satisfy its needs, leading to substantial imports (Qiao et al., 2023; Wang et al., 2023). Argentina and Canada are other major players in the global soybean market. The main export destinations for both countries include China, the European Union, and several countries across Asia. Canadian soybeans are often noted for their high protein content and suitability for food-grade applications (Hooker et al., 2023).

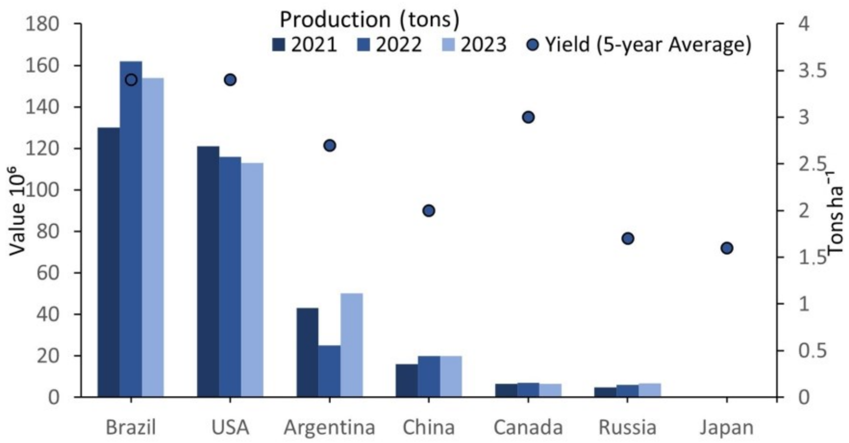

Figure 1. Soybean production indicators across countries (USDA, 2024).

Russia has been increasing its soybean production in recent years but is not among the top global producers. While the total production volume may not match that of China or the USA, Russia's soybean sector shows promise in contributing to both domestic consumption and international markets. One potential international consumer is Japan (Boiarskii et al., 2018). Japan's soybean production, in contrast, is characterized by a smaller cultivation area and limited yield. The country faces constraints due to its mountainous terrain and limited arable land. Japan relies heavily on imports to meet its soybean demand, indicating a more modest contribution from domestic production.

3.2. Comparison of the soybean's nutritional composition from USA, Japan, China, and Russia

Understanding the nutritional composition of soybean varieties is crucial for identifying market opportunities and enhancing the competitiveness of Russian soybeans in the global market. Comparing the nutritional content of soybean varieties across different countries provides valuable insights into the market potential of Russian soybeans. Varieties with higher protein content, for example, are more nutritious and desirable in both domestic and international markets.

In this study, we selected soybean samples from the United States, Canada, China, and Japan for detailed analysis in our laboratory. These countries were chosen due to their significant roles in the global soybean market and their diverse agricultural practices. The United States and Canada are leading producers known for their high-quality soybean varieties, often distinguished by high protein and oil content (Cober et al., 2023). China, as the largest importer of soybeans, offers insights into the varieties that are highly demanded in the global market (Wang et al., 2023). Japan's focus on developing specific soybean varieties for local culinary uses provides a unique perspective on quality and nutritional attributes (Nair et al., 2023).

Including soybean samples from these countries allows for a comprehensive comparative analysis, highlighting the nutritional diversity and potential market advantages of Russian soybean varieties. By analyzing samples from these key players, we can better understand how Russian soybeans compare in terms of protein and oil, thereby identifying niche markets and opportunities for enhancing Russia's presence in the international soybean market.

Table 1. Composition values of soybean varieties from different countries.

Variety name	Country	Weight of 100 seeds	Seed coat ratio	Protein content in seeds (%)	Oil content in seeds (%)	Mineral content (%)	Carbohydrates content in seeds (%)
Venera	Russia	22.2	7.3	44.5	17.9	5.1	32.5
Primorskaya 81	Russia	20.7	7.6	43.7	18.6	4.8	32.9
American*	America	19.7	8.0	42.6	23.7	5.0	28.7
Canadian*	Canada	18.2	7.4	44.6	19.4	5.0	31.0
Suinong**	China	17.7	8.6	38.9	21.2	5.0	34.9
Enrei	Japan	35.6	6.4	46.4	19.7	5.0	28.9
Suzumaru	Japan	14.0	7.7	39.8	20.1	5.7	34.4

* As per confidentiality guidelines, we cannot disclose the names associated with the matter at hand.
** The study selected the Chinese northern variety due to its proximity to the given varieties from the Far East regions, which shares a border with China's Heilongjiang region.

Table 1 shows that, in general, tested varieties in the experiment contain about 35%–40% protein, 20% fat, and 25%–30% carbohydrates, although the composition varies slightly by region and variety. Soybeans produced in Japan have high protein content, soybeans produced in the USA have high oil content, and soybeans produced in China have high carbohydrate content. The analysis of soybean varieties from different countries highlights Russia's competitive edge in producing high-protein soybeans. The Russian varieties Venera and Primorskaya 81 boast impressive protein content (44.5% and 43.7%, respectively), surpassing many of their international counterparts. This high protein level positions Russian soybeans as a valuable commodity in domestic and global markets, particularly for consumers and industries prioritizing nutritional quality. This comparative analysis underscores the potential for Russian soybeans to capture niche markets that demand non-GMO, high-protein varieties, thereby enhancing Russia's export opportunities and market presence.

3.3. Soybean varietal diversity in Russia

As of 2022, the State Register of Breeding Achievements authorized utilizing two hundred and eighty soybean varieties throughout the Russian Federation. This collection includes 194 varieties of Russian origin and 86 foreign varieties (Ministry of Agriculture of Russia, 2022). The data presented in **Figure 2** indicates a consistent growth in the number of registered soybean varieties in Russia over the years. This trend can be attributed to an increased interest in varietal diversity, which has arisen in response to a growing demand for soybeans and the consequent expansion of cultivated areas, especially in Russia's Far East. This has led to the development of various types of soybeans to meet the needs of global consumers. Traditionally, the Amur River valley in the Far Eastern region of Russia has been the central soybean-growing area (Volkova and Smolyaninova, 2023). Due to the intensive creation of numerous soybean varieties, they are grown in the European part of Russia (Shafigullin et al., 2016).

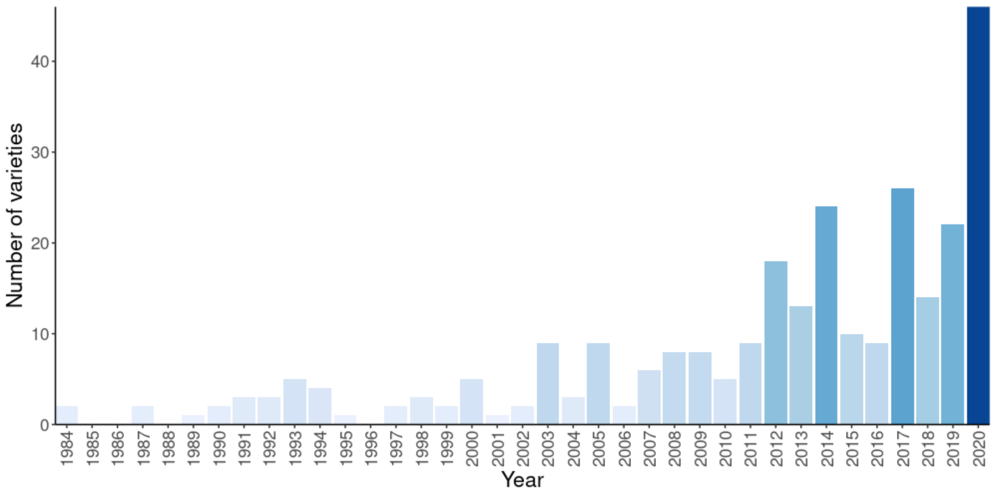

Figure 2. Number of registered soybean varieties in Russia between 1984 and 2022 (Source: State Register for Selection Achievements Admitted for Usage (National List)).

The data from **Figure 2** indicates a marked upswing in the number of newly registered varieties in 2020, reaching a record high of 46 as compared to preceding years. This trend is related to progress and growth in the industry. Furthermore, the figure shows a steady increase in the number of registered varieties since 2010. In this study, the producers of soybean varieties, commonly referred to as originators, were divided into two stages, namely, prior to and after the year 2010. Subsequently, we illustrated these stages on a map to show the trends in the progression of contributions.

The maps provided in this study display the number of registered varieties from specific originators, including international ones (on the left side of the map). Additionally, for a more comprehensive understanding of registered varieties, the map of Russia is segmented into Federal Districts (on the right side of the map).

Between 1991 and 2010, the Southern Federal District of Russia emerged as the primary position of soybean variety originators in the country. Specifically, the Krasnodar region registered a total of 16 distinct soybean varieties, while the Volgograd and Rostov regions registered a smaller number of varieties. These figures underscore the role played by the Southern federal subject in the development and registration of soybean varieties in Russia during the timeframe (**Figure 3**). In essence, the Southern Federal District was at the forefront of advancements in the soybean industry, leading the charge in the creation of new and diverse varieties of soybeans in the country.

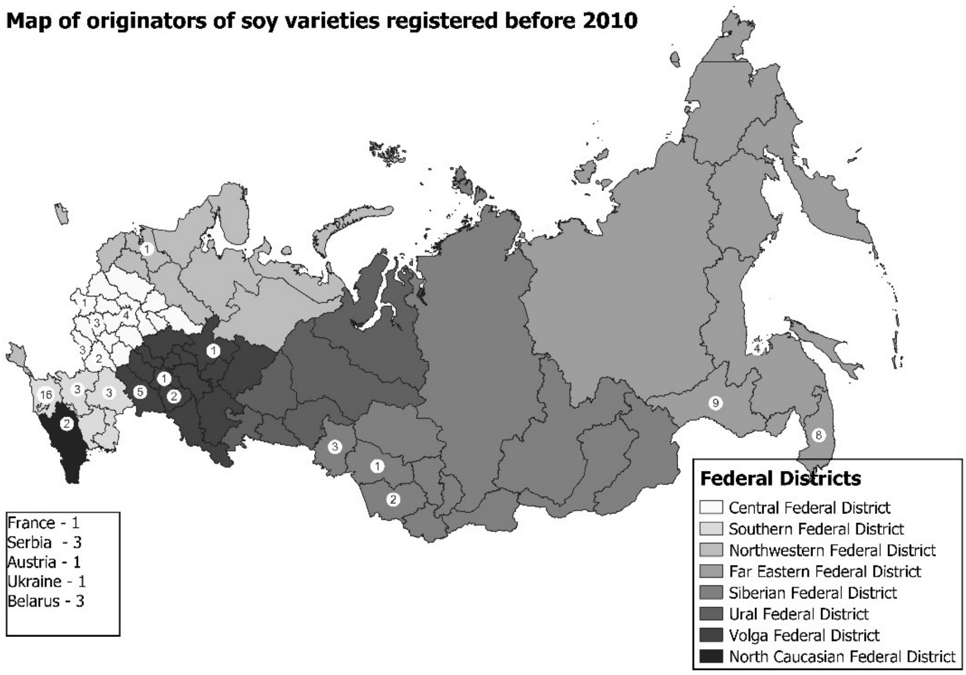

Figure 3. The total number of varieties registered by originators for a certain period in Russia before 2010.

The registration of foreign-origin soybean varieties has significantly increased in Russia since 2010. This trend is attributed to the crop's profitability, which created an interest from foreign companies to occupy that niche. In response, a growing number of foreign originators, such as France, Serbia, and Austria, have registered in the State Register of Breeding Achievements. Russia's Southern and Far East regions registered many soybean varieties between 2010 and 2021. The Krasnodar region registered 32 varieties, followed by the Amur region with 23 varieties, making these regions the primary contributors to varietal formation (**Figure 4**).

Russia has a well-established network of soybean breeding units that are strategically distributed across various regions to optimize breeding efforts according to local climatic and soil conditions. The Far Eastern Federal District is home to leading research facilities in the Amur region and Primorskii krai. The Amur region is renowned for its fertile lands and is the location of the All-Russian Scientific Research Institute of Soybeans, which specializes in developing high-yielding soybean varieties suitable for the temperate climate. In Primorskii krai, the Primorskii Research Institute of Agriculture is dedicated to creating early-maturing soybean varieties that can thrive in the region's cooler climate and shorter growing season.

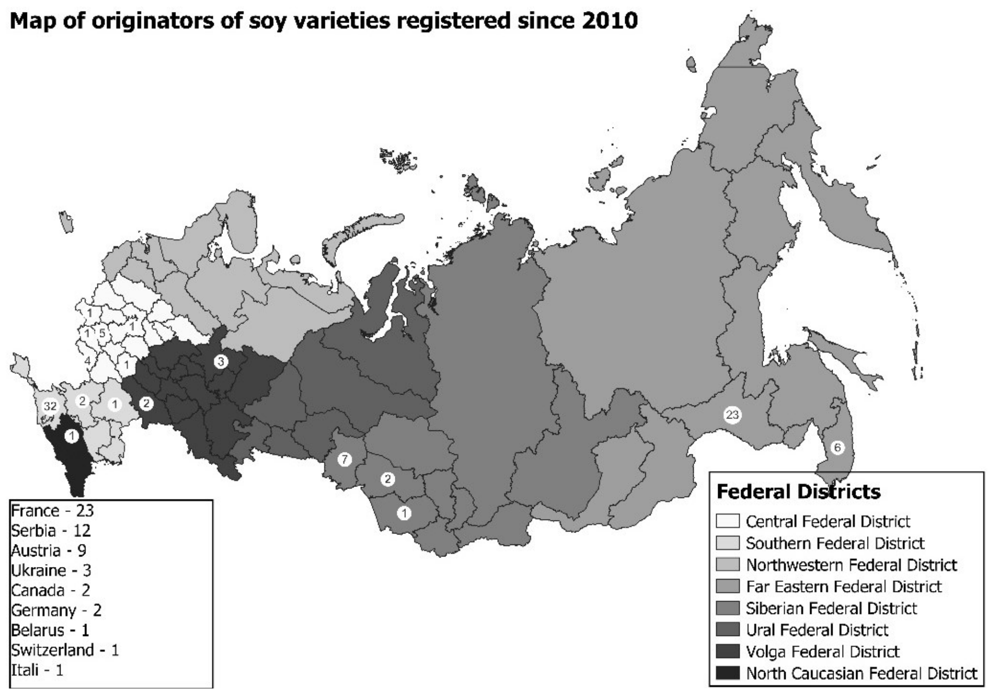

Figure 4. The total number of varieties registered by originators for a certain period in Russia after 2010.

The Southern Federal District includes the Krasnodar krai, known for its favorable agricultural conditions and as a significant hub for soybean breeding. The Kuban State Agrarian University plays a key role in developing soybean varieties with high oil and protein content. In the Rostov region, breeding programs focus on drought-resistant soybean varieties, which are essential for the semi-arid climate.

The Central Federal District encompasses the Belgorod region, renowned for its advanced agricultural practices and breeding units. These entities focus on developing crop varieties optimized for high productivity and disease resistance. Within the Volga Federal District, the Samara region is notable for its breeding units, which specialize in developing varieties suited to the region's specific climatic conditions, including resilience to temperature fluctuations.

Russian farmers also rely on foreign sources for their soybeans, primarily obtaining seeds from companies such as Euralis Semans in France, Novy Sad in Serbia, Saatbau in Austria, and Prograin in Canada. These international sources provide a diverse range of soybean varieties that contribute to the genetic diversity and adaptability of soybeans cultivated in Russia.

The classification of soybean varieties is based on two key factors—the duration of the maturity period and the sum of active temperatures. The duration from emergence to flowering and maturation is a critical agronomic trait for assessing the suitability of a soybean variety across different latitudes (Hartwig, 1970). The described characteristic is specific to the location, as it can vary for the same plant variety under different photothermal conditions (Cober et al., 2001; Song et al., 2019). These factors help in dividing the soybean varieties into nine groups in Russia, as specified in **Table 2**. While classification by the duration of the maturity period is the most commonly used method, classification by the sum of active temperatures provides a more complete understanding of the features of the genotype. This is because the sum of active temperatures is a genetic trait that is fixed in the genome of the soybean variety (Jia et al., 2014). Therefore, it offers a more comprehensive and accurate classification of soybean varieties.

Table 2. Maturity groups of soybeans by Russian and international standardizations.

Russia		**Maturity group**	**Sum of active temperatures, °C**
Maturity ecotype	**Days**		
Very early	80 or less	0000, 000	1700 or less
From very early to early	81–90	00	1701–1900
Early	91–110	0	1901–2200
Medium early	111–120	I	2301–2400
Medium	121–130	II	2301–2400
Middle late	131–150	III, IV	2401–2600
Late	151–160	V	2601–3000
From late to very late	161–170	VI	3001–3500
Exclusively late	≥170	VII–X	≥3500

The study included international standardization to offer a broad view on soybean maturity groups. This is crucial for facilitating a universal comparison of soybean varieties across different regions. The international classification system employs similar criteria but may have slight variations in terminology and days to mature, underscoring the importance of global alignment and understanding.

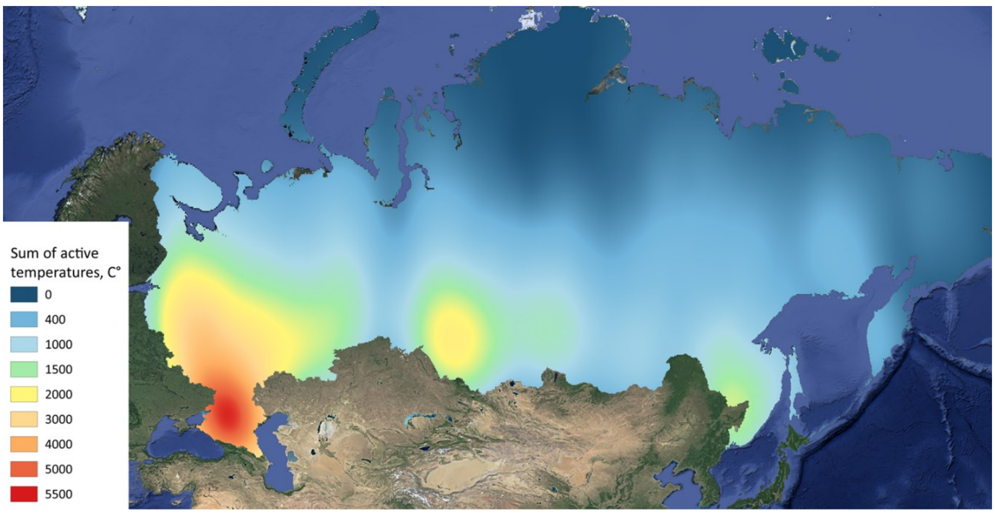

Figure 5. Sum of active temperatures more than 10 °C in Russia.

The lower threshold of active average daily temperatures for the growth and development of soybean plants is 15–17 °C. The critical period is flowering and bean formation. The area of soybean distribution is limited by the sum of active temperatures and the date of the first frost. When zoning varieties by agroclimatic zones, very early and early maturing varieties require the sum of active temperatures 1700–2200 °C for full maturation, medium varieties 2301–2600 °C, and late maturing varieties 2601–3500 °C. **Figure 5** shows that the late-maturing varieties are almost not suitable for use in Russia, except in some southern regions. Overall, in Russia, early-maturing varieties are more common due to the lower sum of active temperature zones.

Ecological plasticity of a variety refers to its ability to adapt to different soil-climatic, weather, and economic conditions (Beliavskaya, 2017). This is an essential trait for any crop variety because it ensures the plant can thrive in various environmental conditions. In Russia, the most common soybean varieties are medium early and early varieties. However, in the country's northern regions, very early varieties show great yield promise (**Figure 6**). It is important to note that regionalized varieties are specifically adapted to certain conditions and are only able to produce high yields in a limited area. This means that farmers must carefully consider the specific environmental conditions of their land when choosing which variety of soybeans to plant. By selecting a variety that is well-adapted to their specific area, farmers can maximize their yield and ensure the success of their crop.

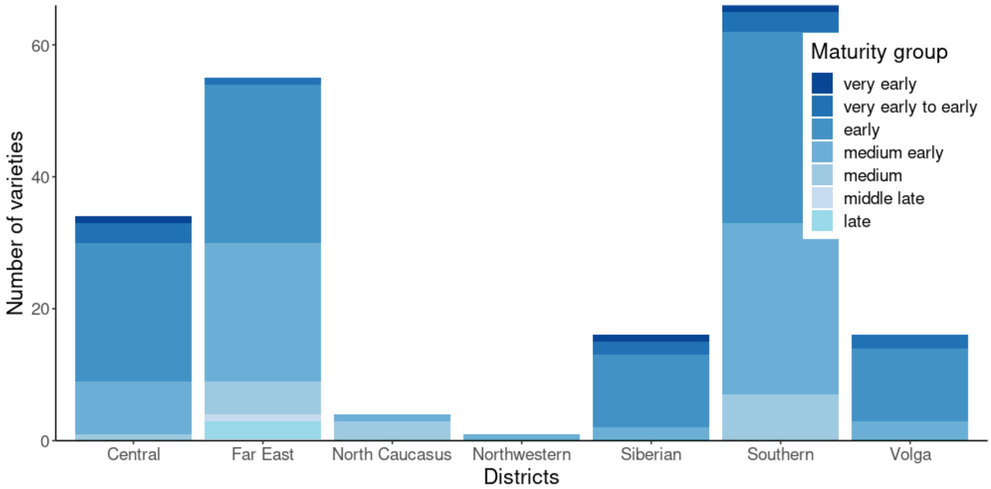

Figure 6. Relationship between the cultivar type, as determined by the maturity groups and the registration area between the years 1972 and 2021 (Source: Federal State Budgetary Institution "State Commission of the Russian Federation for Testing and Protecting Plant Breeding Achievements).

There were almost no registered varieties in the Ural, Northern, and North-Western regions. This is due to the fact that the climate in these regions does not allow for efficient soybean cultivation. The duration of the maturity period is one of the main indicators of soybean varieties that determine the possibility of their cultivation in certain environmental conditions. The "duration of the maturity period" in soybeans depends largely on the latitude of the cultivation area (Jia et al., 2014). In Russia, predominantly early maturing varieties (according to the international classification) with a maturity period of 80 to 130 days are cultivated (**Figure 6**).

The study conducted an analysis of soybean yield, protein, and oil composition among various varieties across different districts. Each district exhibited a distinct array of soybean varieties, and comprehensive data were collected and compared across these diverse regions. In general, the Krasnodar Krai in the Southern Federal District and Belgorod and Kursk Oblasts in the Central Federal District have the highest yields of grain and leguminous crops. The lowest yields are in the Siberian Federal District. In general, the farther to the East of Russia, the lower the average yield of grain crops. This is due to less favorable geographical and climatic conditions. The highest average yield in the Southern region of Russia is due to the location of the region in a favorable climate for agriculture compared to other regions. The lowest indicator shows a slight difference between the Volga and Siberian regions. In the other regions of the Far East and Central Federal District, the average yield of soybean seeds has an index slightly lower than the Southern district (**Figure 7**).

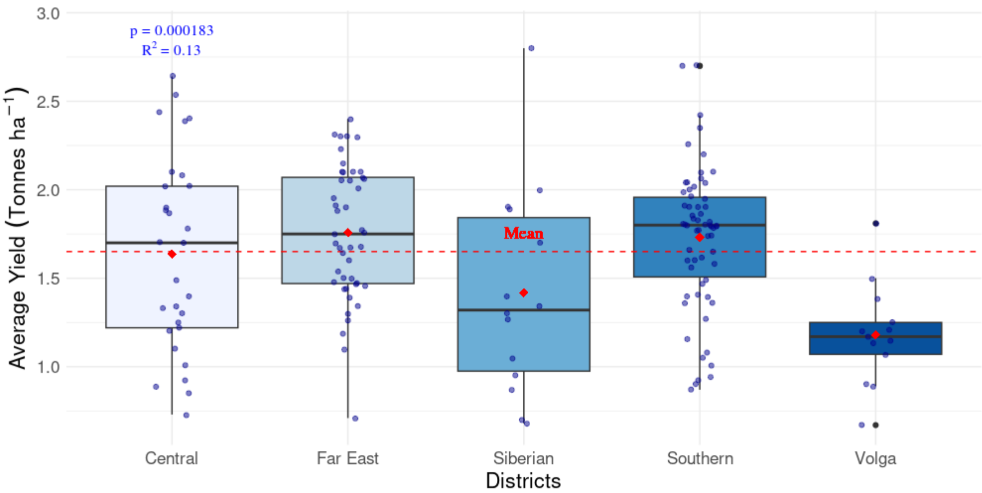

Figure 7. Average yield of registered soybean varieties specific to each district in Russia (Source: State Register for Selection Achievements Admitted for Usage (National List)).

Varieties registered by Far Eastern originators have a significantly higher percentage of protein content in grains than in other regions. The lowest percentage of protein content is observed in varieties registered in the Volga Federal District (**Figure 8**). This is connected and has an impact that, recently, there has been a need for rapidly developing feed production in the Central District. Therefore, the emphasis of breeding work was on the yield of soybeans and not the protein content in the seed. In the Far Eastern Federal District and the Southern Federal District, there is a long tradition of eating soybeans. Also, in the Far Eastern Federal District, there is pressure from foreign importers who have requirements for the protein content of the seed. The ratio of protein and oil is inversely related and is also determined by the variety and climatic conditions (Jin et al., 2023), genetic analysis of protein content and oil content in soybean by genome-wide association study. Several experiments proved that the decreasing temperature has a relationship with increasing protein content in soybean seed (Alsajri et al., 2020; Staniak et al., 2021; Vollmann et al., 2000). The focus on protein content in soybean seeds in the work of breeders in Russia began relatively recently. The Russian soybean industry experienced a particularly large jump after the introduction of a zero-export duty in 2015, which stimulated an increase in prices on the domestic market and an increase in foreign trade demand for soybeans. The export orientation of soybeans is that China is the main consumer of soybeans in the world. The demand for high-protein varieties drove China, hence the reorientation towards high protein content and the construction of its own factories for the deep processing of soybeans (isolate, lecithin, etc.). Before this, there were mainly oil extraction plants and a high oil content was required for the soybean grain. The target is considered to be a protein content of 40%.

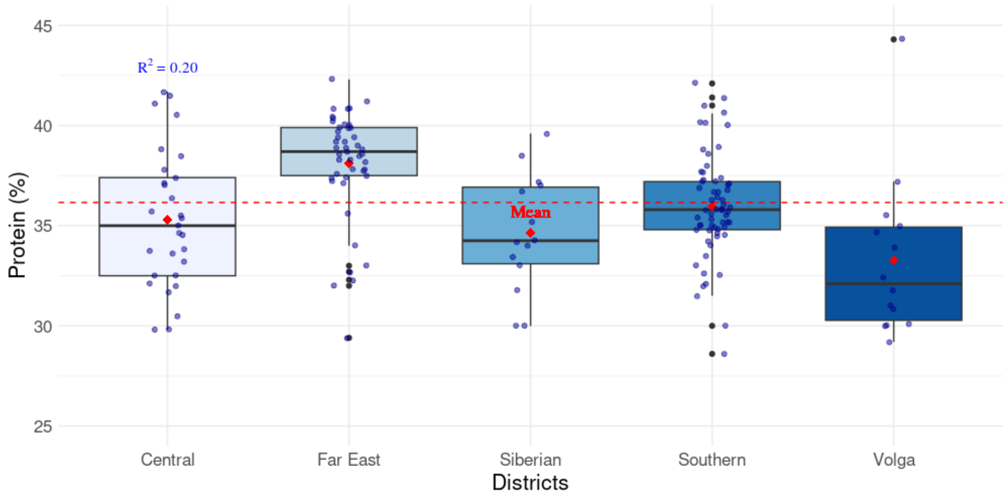

Figure 8. Protein content of registered soybean varieties specific to each district in Russia (Source: State Register for Selection Achievements Admitted for Usage (National List)).

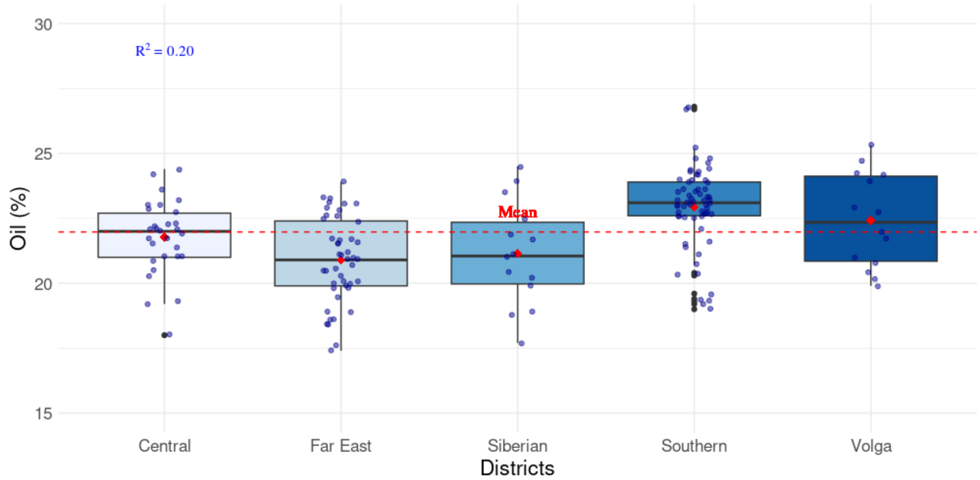

Figure 9. Oil content of registered soybean varieties specific to each district in Russia (Source: State Register for Selection Achievements Admitted for Usage (National List)).

For a long period of time, soybean cultivation in Russia was mostly for oil extraction. Generally, Russian soybean is used for producing livestock feed and after being pressed for oil (Boiarskaia et al., 2020). On average, soybeans contain around 18%–22% oil content, but certain varieties can have oil content ranging from 20% to over 25% (Muchlish Adie and Krisnawati, 2014). The Volga Federal District and the Southern Federal District have the highest average oil content in seeds (**Figure 9**). Mourtzinis et al. (2017) noted that there is a correlation between warm temperatures and lipid content in soybean seeds and inverse dependence on protein content.

4. Discussion

Soybean cultivation in Russia is a distinctive agricultural practice that sets it apart from other countries. Unlike many nations that allow the growth of genetically modified soybean varieties, Russia prohibits their cultivation. As a result, all soybeans grown in Russia are non-genetically modified organisms (Chokheli et al., 2020), making them a unique and valuable commodity in the global market (Volkova and Smolyaninova, 2023). In light of global concerns surrounding GMOs and consumer preferences for non-GMO products, the demand for Russian soybeans is likely to remain strong. One of the reasons why Russian soybean varieties are in high demand is their adaptability to the severe climatic conditions that prevail in the Far East region. This area has a large number of crops but is not as densely populated by foreign companies. This makes Russian soybean varieties a preferred choice among local farmers who value their unique characteristics (Sinegovskaia, 2021; Volkova and Smolyaninova, 2023). In addition, Russian soybeans are known for their robustness and resilience, which makes them more resistant to diseases, pests, and adverse weather conditions. Overall, the cultivation of non-GMO soybeans in Russia is a fascinating and successful agricultural phenomenon that has created a unique product that is both resilient and adaptable to harsh conditions (Chutcheva et al., 2023).

It is crucial to keep in mind that farmers and seed producers in Russia are permitted to breed and grow only those varieties of crops that have been officially approved and included in the State Register of Breeding Achievements in the particular zone of the country. This regulation guarantees that the crops produced are of high quality and adhere to the necessary standards (Balakay et al., 2020). It is also noteworthy that crop insurance and government subsidies are exclusively available in areas where registered varieties are grown and only in accordance with appropriate zoning regulations. Therefore, it is incumbent upon farmers to be well-versed in the zoning regulations in their region and ensure that they are growing the appropriate varieties in the correct areas. By complying with these regulations, they can benefit from government support and safeguard their crops against potential risks.

In Russia, due to limited thermal resources, the yield of many varieties is no more than 2.5 t/ha (Volkova and Smolyaninova, 2023). The Russian soybean breeding sector is poised to implement strategies aimed at reducing the maturity period for sowing in northern territories (Boiarskii et al., 2020). This initiative is anticipated to yield significant gains, including increased gross production, enhanced yield, and a targeted augmentation of protein content by 40% or more. Over the years, domestic breeding has neglected the development of high-protein soybean varieties, focusing instead on increasing yield rather than enhancing quality. Consequently, French and Canadian soybean varieties outperform domestic ones in terms of oil and protein content. A crucial issue lies in the lack of adequate funding for domestic research institutes to conduct breeding work and generate the necessary volume of seeds needed by agricultural enterprises. This poses a significant challenge for ensuring the availability of quality seeds for the agricultural sector (Boiarskii et al., 2020; Sinegovskaia et al., 2016; Sinegovskii et al., 2018).

Looking ahead, the trajectory of soybean variety development in Russia may hinge on many factors. Climate change adaptation strategies could prompt an expansion of soybean cultivation into previously colder regions, thereby reshaping the geographical landscape of production. Furthermore, the outcomes of climate change on extreme flood occurrences and associated damages to agricultural areas, particularly in the Primorskii krai, underscore the need for proactive measures within the agricultural sector (Lyude et al., 2021).

Future projections of soybean variety in Russia might depend on several factors. Climate change adaptation could lead to an expansion of soybean cultivation into previously colder regions (Minoli et al., 2022; Qian et al., 2016). Climate change impacts extreme flood occurrence and flood-related damage to the Primorskii krai agriculture. Market demand for soybean products, including soybean oil and soybean meal for livestock feed internationally and domestically, could incentivize increased production. Also, nowadays, high demand worldwide for soy meat requires high-quality soybeans with high protein content in the seed. Government policies and subsidies, as well as international trade agreements and partnerships, are key factors that can shape the future of soybean farming in Russia. In addition, disease and pest management, as well as sustainability considerations, will play crucial roles in determining the trajectory of soybean variety in the country. Therefore, stakeholders in the industry must keep abreast of these factors, as they can significantly impact the production, trade, and consumption of soybeans in Russia. By staying informed and engaged, industry players can better position themselves to take advantage of opportunities and navigate potential challenges in this dynamic sector.

5. Conclusion

The first occurrence of harvesting soybeans and registered varieties was in the Far East. The primary cultivation was in the Far East. Later, with the development of soybean breeding, it spread to other cultivation regions. Foreign originators of varieties make up about 40% of the Russian State Register. The main varieties were registered in the Krasnodar Territory and the Amur Region. There has been a steady increase in registered soybean varieties since 2010, with a peak in 2020 and reaching 46 new varieties. The historical distribution of originators highlights the dominance of the Southern Federal District before 2010 and the subsequent surge in foreign originators post-2010, reflecting the increasing profitability of soybean cultivation in Russia. The main varieties registered in Russia are maturity period duration prevalence of early and medium early varieties, with regionalized adaptations crucial for optimizing yields in specific areas. The lack of registered varieties in the Ural, Northern, and North-Western regions underscores the climatic limitations for soybean cultivation in these areas. Yield and protein content analysis showcase regional disparities, with the Krasnodar Krai and Central Federal District leading in yields and Far Eastern varieties displaying higher protein content. The focus on protein content in soybeans gained prominence after 2015, aligning with global demand trends, particularly from China. Currently, soybean breeding in Russia is developing dynamically with support from the state, having a competitive market from foreign breeders, creating conditions for further development. The direction of soybean breeding in Russia will be aimed at reducing the maturity period, increasing yields, and increasing the protein content in seeds, with influencing factors such as climate change, world market demand, government policies, and subsidies.

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References

Adi Sofyan Ansori, M., & Aji Suseno, D. (2018). Impact of Policy of Soybean Price Stability on Imported and Local Soybean Price. Economics Development Analysis Journal, 6(2), 209–214. https://doi.org/10.15294/edaj.v6i2.22218

Alsajri, F. A., Wijewardana, C., Irby, J. T., Bellaloui, N., et al. (2020). Developing functional relationships between temperature and soybean yield and seed quality. Agronomy Journal, 112(1), 194–204. https://doi.org/10.1002/agj2.20034

Azam, M., Zhang, S., Qi, J., et al. (2021). Profiling and associations of seed nutritional characteristics in Chinese and USA soybean cultivars. Journal of Food Composition and Analysis, 98, 103803. https://doi.org/10.1016/j.jfca.2021.103803

Balakay, G. T., Selitskiy, S. A., Dokuchayeva, L. M., & Yurkova, R. Y. (2020). Rostov Region Territory Zoning on Agro-Climate Subzones for Perspective Soy Varieties of Various Maturity Groups. Scientific Journal of Russian Scientific Research Institute of Land Improvement Problems, 3(39), 52–67. https://doi.org/10.31774/2222-1816-2020-3-52-67

Beliavskaya, L. (2017). The results of study of ecological stability and plasticity of Ukrainian soybean varieties. Annals of Agrarian Science, 15(2), 247–251. https://doi.org/10.1016/j.aasci.2017.05.003

Boiarskaia, A., Hasegawa, H., Boiarskii, B., & Lyude, A. (2020). History of development of Soybean Production in the Amur Region and Far East District in the USSR. IOP Conf. Ser.: Earth Environ. Sci., 548(2), 022079. https://doi.org/10.1088/1755-1315/548/2/022079

Boiarskii, B., Hasegawa, H., & Lyude, A. (2018). Demand for Russian soybean based on the needs of food industry in Japan. Scientific Support for Soybean Production: Problems and Prospects, 36–41.

Boiarskii, B., Hasegawa, H., Lyude, A., et al. (2020). Current Situation and Perspectives for Soybean Production in Amur Region, Russian Federation. AMA, Agricultural Mechanization in Asia, Africa and Latin America, 51(2), 33–38.

Boiarskii, B., Hasegawa, H., Sinegovskii, M., et al. (2019). Application of NDVI Data to Analyse the Effects of Sowing Methods and Seeding Rates on Soybean Crop Yield. Journal of Engineering and Applied Sciences, 14(12), 4290–4294. https://doi.org/10.36478/jeasci.2019.4290.4294

Butovets, E., Lukyanchuk, L., & Vasina, E. (2022). Comparative Assessment of Promising Soybean Varieties at the Final Selection Stage. In: Lecture Notes in Networks and Systems. Springer International Publishing. https://doi.org/10.1007/978-3-030-91402-8_26

Bychkova, E. A., & Borisova, A. V. (2021). Soy protein concentrates: production technologies and application prospects.

Polzunovskiy Vestnik, 2, 88–94.

Chokheli, V., Rajput, V., Dmitriev, P., et al. (2020). Status and Policies of GM Crops in Russia. In: Policy Issues in Genetically Modified Crops: A Global Perspective. Academic Press. https://doi.org/10.1016/B978-0-12-820780-2.00003-0

Chutcheva, Y., Belyshkina, M., & Degtyareva, E. (2023). Soybean seed production in the Russian Federation – current state and development prospects. Russian Journal of Management, 11(2), 12–21. https://doi.org/10.29039/2409-6024-2023-11-2-12-21

Cober, E. R., Stewart, D. W., & Voldeng, H. D. (2001). Photoperiod and temperature responses in early-maturing, near-isogenic soybean lines. Crop Science, 41(3), 721–727. https://doi.org/10.2135/cropsci2001.413721x

Cober, E. R., Daba, K. A., Warkentin, T. D., et al. (2023). Soybean seed protein content is lower but protein quality is higher in Western Canada compared with Eastern Canada. Canadian Journal of Plant Science, 103(4), 411–421. https://doi.org/10.1139/cjps-2022-0147

Demianova-Roy, G., Mataryeva, I., Atamanova, E., et al. (2022). Soybean (Glycine Max) as an Economic and Ecological Object of Introduction to the Northwestern Region of Russia. Periódico Tchê Química, 19(41), 63–82.

Dorohov, A. S., Belyshkina, M. E., & Bolsheva, K. K. (2019). Soybean production in the Russian Federation: Main trends and development prospects. Vestnik of Ulyanovsk State Agricultural Academy, 3(47), 25–33. https://doi.org/10.18286/1816-4501-2019-3-25-33

Fadeev, A. A. (2023). A new early-ripening soybean variety of the northern ecotype Civil. Siberian Herald of Agricultural Science, 53(1), 23–28. https://doi.org/10.26898/0370-8799-2023-1-3

Gong, L., Liu, D., Jiang, L., et al. (2022). Distribution characteristics of climate potential productivity of soybean in frigid region and its response to climate change. Environmental Science and Pollution Research, 29(5), 7452–7464. https://doi.org/10.1007/s11356-021-15879-y

Hartwig, E. E. (1970). Growth and reproductive characteristics of soybeans [Glycinemax (L) Merr.] grown under short-day conditions. Tropical Science, 12(1).

Hodges, T., & French, V. (1985). Soyphen: Soybean Growth Stages Modeled from Temperature, Daylength, and Water Availability. Agronomy Journal, 77(3), 500–505. https://doi.org/10.2134/agronj1985.00021962007700030031x

Hooker, J. C., Nissan, N., Luckert, D., et al. (2023). A Multi-Year, Multi-Cultivar Approach to Differential Expression Analysis of High- and Low-Protein Soybean (Glycine max). International Journal of Molecular Sciences, 24(1), 222. https://doi.org/10.3390/ijms24010222

Jia, H., Jiang, B., Wu, C., et al. (2014). Maturity group classification and maturity locus genotyping of early-maturing soybean varieties from high-latitude cold regions. PLoS ONE, 9(4), e94139. https://doi.org/10.1371/journal.pone.0094139

Jin, H., Yang, X., Zhao, H., et al. (2023). Genetic analysis of protein content and oil content in soybean by genome-wide association study. Frontiers in Plant Science, 14, 1–12. https://doi.org/10.3389/fpls.2023.1182771

Karges, K., Bellingrath-Kimura, S. D., Watson, C. A., et al. (2022). Agro-economic prospects for expanding soybean production beyond its current northerly limit in Europe. European Journal of Agronomy, 133, 126415. https://doi.org/10.1016/j.eja.2021.126415

Katyshev, A. I., Katysheva, N. B., Fedoseeva, I. V., et al. (2021). Analysis of differential expression of soybean genes as basis for development of genetic markers of early ripening. Siberian Journal of Life Sciences and Agriculture, 13(1), 35–57. https://doi.org/10.12731/2658-6649-2021-13-1-35-57

Lambirth, K. C., Whaley, A. M., Blakley, I. C., et al. (2015). A Comparison of transgenic and wild type soybean seeds: Analysis of transcriptome profiles using RNA-Seq. BMC Biotechnology, 15(1). https://doi.org/10.1186/s12896-015-0207-z

Lyude, A., Boiarskii, B., Matsishina, N., et al. (2021). Climate change impact on extreme flood occurrence and flood-related damage to the Primorye Region agriculture. IOP Conference Series: Earth and Environmental Science, 677(5), 052028. https://doi.org/10.1088/1755-1315/677/5/052028

Mangena, P. (2021). Analysis of correlation between seed vigour, germination and multiple shoot induction in soybean (Glycine max L. Merr.). Heliyon, 7(9), e07913. https://doi.org/10.1016/j.heliyon.2021.e07913

Mikhailova, M., Sinegovskaia, V., Boiarskii, B., et al. (2020). Evaluation of the influence of biologically active substances on the physiological processes of soybean plants with the use of multispectral camera and unmanned aerial vehicle. IOP Conference Series: Earth and Environmental Science, 548(3), 032028. https://doi.org/10.1088/1755-1315/548/3/032028

Ministry of Agriculture of Russia. (2022). State Register for Selection Achievements Admitted for Usage (National List) (Plant varieties, Vol. 1). FGBNU Rosinformagrotech.

Minoli, S., Jägermeyr, J., Asseng, S., et al. (2022). Global crop yields can be lifted by timely adaptation of growing periods to

climate change. Nature Communications, 13(1). https://doi.org/10.1038/s41467-022-34411-5
Mourtzinis, S., Gaspar, A. P., Naeve, S. L., & Conley, S. P. (2017). Planting date, maturity, and temperature effects on soybean seed yield and composition. Agronomy Journal, 109(5), 2040–2049. https://doi.org/10.2134/agronj2017.05.0247
Muchlish Adie, M., & Krisnawati, A. (2014). Soybean opportunity as source of new energy in Indonesia. International Journal of Renewable Energy Development, 3(1), 37–43. https://doi.org/10.14710/ijred.3.1.37-43
Nair, R. M., Boddepalli, V. N., Yan, M. R., et al. (2023). Global Status of Vegetable Soybean. Plants, 12(3), 609. https://doi.org/10.3390/plants12030609
Novikova, L. Y., Bulakh, P. P., Nekrasov, A. Y., & Seferova, I. V. (2020). Soybean Response to Weather and Climate Conditions in the Krasnodar and Primorye Territories of Russia over the Past Decades. Agronomy, 10(9), 1278. https://doi.org/10.3390/agronomy10091278
Pagano, M. C., & Miransari, M. (2016). The importance of soybean production worldwide. Abiotic and Biotic Stresses in Soybean Production: Soybean Production, 5, 1–26. https://doi.org/10.1016/B978-0-12-801536-0.00001-3
Popov, A., & Bumbar, I. (2023). Ways to Increase the Efficiency of Grain and Soybean Harvesting in the Amur Region. In: Lecture Notes in Networks and Systems. Springer, Cham. https://doi.org/10.1007/978-3-031-21432-5_20
QGIS. (2022). QGIS Geographic Information System. QGIS Association.
Qian, Y., Mao, L., & Zhou, G. (2016). Changes in global main crop yields and its meteorological risk assessment. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering, 32(1). https://doi.org/10.11975/j.issn.1002-6819.2016.01.032
Qiao, C., Cheng, C., & Ali, T. (2023). How climate change and international trade will shape the future global soybean security pattern. Journal of Cleaner Production, 422, 138603. https://doi.org/10.1016/j.jclepro.2023.138603
R Core Team. (2023). R: A language and environment for statistical computing. In: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Rezvichkiy, T., Tikidzhan, R., Pozdniakova, A., & Mitlash, A. (2021). Main diseases on soybean crops. The Scientific Heritage, 59, 6–8.
Shafigullin, D. R., Romanova, E. V., Gins, M. S., et al. (2016). Evaluation and Selection of Different Varieties and Lines of Soybean for Breeding for Valuable Traits in the Central European Part of Russia. Vegetable Crops of Russia, 2, 28–32. https://doi.org/10.18619/2072-9146-2016-2-28-32
Shchegorets, O., Tikhonchuk, P., Bumbar, I., & Yakimenko, A. (2020). Innovation as a factor in increasing the efficiency of soybean production in the Amur Region. E3S Web of Conferences, 203, 05010. https://doi.org/10.1051/e3sconf/202020305010
Shi, W., Tao, F., & Zhang, Z. (2013). A review on statistical models for identifying climate contributions to crop yields. Journal of Geographical Sciences, 23(3), 567–576. https://doi.org/10.1007/s11442-013-1029-3
Sinegovskaia, V. (2021). Scientific provision of an effective development of soybean breeding and seed production in the Russian Far East. Vavilovskii Zhurnal Genetiki i Selektsii, 25(4), 374–380. https://doi.org/10.18699/VJ21.040
Sinegovskaia, V., Sinegovskii, M., & Antonova, N. (2016). The role of the variety in improving the efficiency of soybean production in the Amur region. Vestnik Rossiiskoi Sel'skokhozyaistvennoi Nauki, 5(5), 28–30.
Sinegovskii, M. (2020). Perspectives of Soybean Production in the Far East Federal District. Vestnik of the Russian Agricultural Science, 1, 13–16. https://doi.org/10.30850/vrsn/2020/1/13-16
Sinegovskii, M. (2024). Soybean as a means to compensate for protein deficit (Historical aspect). Agronauka, 2(1), 16–22. https://doi.org/10.24412/2949-2211-2024-2-1-16-22
Sinegovskii, M., Malashonok, A., & Sinegovskaia, V. (2021). Assessment of the export potential of Russian soybeans. IOP Conference Series: Earth and Environmental Science, 677(2). https://doi.org/10.1088/1755-1315/677/2/022025
Sinegovskii, M., Yuan, S., Sinegovskaia, V., & Han, T. (2018). Current Status of the Soybean Industry and Research in the Russian Federation. Soybean Science, 37(01), 1–7.
Song, W., Sun, S., Ibrahim, S. E., et al. (2019). Standard cultivar selection and digital quantification for precise classification of maturity groups in soybean. Crop Science, 59(5), 1997–2006. https://doi.org/10.2135/cropsci2019.02.0095
Staniak, M., Czopek, K., Stępień-Warda, A., et al. (2021). Cold stress during flowering alters plant structure, yield and seed quality of different soybean genotypes. Agronomy, 11(10), 1–14. https://doi.org/10.3390/agronomy11102059
Tikhonchuk, P. V., Shegorets, O. V., Zakharova, E. B., et al. (2016). Agriculture System of the Amur Region (production). Far Eastern State Agrarian University.

Tiwari, S. P. (2017). Emerging Trends in Soybean Industry. Soybean Research, 15(1).
Vaitekhovich, I., Lyude, A., Boiarskaia, A., & Hasegawa, H. (2022). The possibility of introduction and cultivation of vegetable soybean in the Amur Region. IOP Conference Series: Earth and Environmental Science, 1045(1). https://doi.org/10.1088/1755-1315/1045/1/012064
Volkova, E., & Smolyaninova, N. (2023). Amur region in the structure of soybean production of the Russian Federation. E3S Web of Conferences, 462, 02040. https://doi.org/10.1051/E3SCONF/202346202040
Vollmann, J., Fritz, C. N., Wagentristl, H., & Ruckenbauer, P. (2000). Environmental and genetic variation of soybean seed protein content under Central European growing conditions. Journal of the Science of Food and Agriculture, 80(9). https://doi.org/10.1002/1097-0010(200007)80:9<1300::AID-JSFA640>3.0.CO;2-I
Wang, M., Liu, D., Wang, Z., & Li, Y. (2023). Structural Evolution of Global Soybean Trade Network and the Implications to China. Foods, 12(7), 1550. https://doi.org/10.3390/foods12071550
WTO. (2016). Law of the Russian Federation No. 5605-1 of 6 August1993 on Achievements in Selection. Available online: https://www.wto.org/english/thewto_e/acc_e/rus_e/WTACCRUS48_LEG_97.pdf (accessed on 5 March 2024).
Yerzhebayeva, R., Didorenko, S., Amangeldiyeva, A., et al. (2023). Marker-Assisted Selection for Early Maturing E Loci in Soybean Yielded Prospective Breeding Lines for High Latitudes of Northern Kazakhstan. Biomolecules, 13(7), 1146. https://doi.org/10.3390/biom13071146
Zakharova, E., & Nemykin, A. (2022). The Effect of Tillage Minimization on the Weed Infestation of Soybean and Grain Crops in the Conditions of the Amur Region in Russia. In: Lecture Notes in Networks and Systems. Springer, Cham. https://doi.org/10.1007/978-3-030-91402-8_51
Zheng, H. F., Chen, L. D., & Han, X. Z. (2009). The effects of global warming on soybean yields in a long-term fertilization experiment in Northeast China. Journal of Agricultural Science, 147(5), 569–580. https://doi.org/10.1017/S002185960900879X
Zotikov, V. I., & Vilyunov, S. D. (2021). Present-day breeding of legumes and groat crops in Russia. Vavilovskii Zhurnal Genetiki i Selektsii, 25(4), 381–387. https://doi.org/10.18699/vj21.041
Zubareva, K. U. (2020). Soybeans in Russia. Bulletin of Rural Development and Social Policy, 4(28).