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Innovative development of the Russian grain sector

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Abstract

The innovative development of the grain sector develops in a wave-like manner, with alternating periods of growth and decline in the yield indicator. The innovation activity of agricultural organizations is currently increasing. The analysis shows the industry's transition to a new technological stage. The priority directions of scientific and technological development are the technologies of grain yield increase, such as biotechnologies of effective accelerated breeding and intensive technologies in seed production; precision farming; biological and organic farming, as well as advanced technologies' phytomelioration.

Keywords: grain production, innovative development, periodicity, technological order, yield, productivity, capital return.
JEL classification: Q16.

1. Introduction

One of the main problems in the development of Russia's grain production is extensive production growth. While more than 80% of U.S. and 60% of Brazil farmers use elements of precision farming in grain production, in Russia this production accounts for 10–12%. This build-up may make Russian products uncompetitive in price in the future, despite the country's leadership in the world grain market. The application of innovative technologies in grain production makes it possible to reduce its cost by 20–40%. Therefore, the sector may already be on the periphery of the world grain market in the short term.

Identifying priority R&D areas is a priority task for the Russian grain sub-complex. This R&D in the medium and long term will ensure grain crop

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production efficiency. Strategic documents such as “The federal scientific and technical programme for agricultural development 2017–2025,” “The strategy for the development of the agro-industrial and fishery complex of the Russian Federation until 2030” and other documents have been developed for grain crop production efficiency. “The long-term strategy for the development of the grain sector of the Russian Federation until 2035” is the only document for the grain sector that defines priority areas for its development. However, this strategy is generalized without specifying the promising directions of scientific and technological support of grain production. On the other hand, the sector has a significant potential for accelerated scientific and technological development, which needs to be more focused.

The study aims to assess the level of innovation development of the grain sector and identify priority areas of scientific and technological advancement.

2. Materials and methods

The theoretical and methodological basis of the study is:

- the work of domestic and foreign scientists on the problems of long-term development of agricultural sectors, on the issues of working out the methodology of forecasting scientific and technological growth;
- laws of the Russian Federation, decrees of the President and regulations of the Government of the Russian Federation, as well as other regulatory legal acts of a strategic nature.

The source materials are statistical compilations of the USSR and the Russian Federation, historical materials, the Federal State Statistics Service data, the Ministry of Agriculture of the Russian Federation, the author’s materials, and technical and reference literature.

3. Theory

For conducting research, it is necessary to understand the nature of “innovative development.” Innovative development is a strategy of advanced development that involves activation of innovation potential and provision of scientific and technological leadership in the industry’s most significant for the fifth and sixth technological paradigm. This definition was formulated by Glazyev (2011).

Innovative development involves using advances in science and technology to improve production techniques such that the productivity of inputs rises. That in turn increases output, lowers production costs (per unit), and enriches the economy.

Innovative development is a strategy of innovative breakthrough based on the concentration of efforts of people, government, business to develop fundamentally new, competitive technologies and products, innovative renewal of critically outdated production apparatus, increasing the role and responsibility of government for the development and distribution of new generations of equipment and technologies, for the effectiveness of integration processes, for promoting the innovative activity of entrepreneurs, scientists, designers, and engineers. This definition was proposed by Kuzyk and Yakovets (2005).

4. Results and discussion

Scientific and technological development of grain production represents the transfer of the sector to a new quality level, which will increase the efficiency of the main factors of production based on the achievements of agricultural science, engineering and technology (Bagdasaryan, 2017). The characteristics of grain production in our case include labor, capital and land. Indicators that characterize the efficiency of production factors are labor productivity, stock productivity and grain yield (Gorodnikova, 2019). Therefore, it is necessary to analyze these factors.

The efficiency of land use in grain production mainly depends on fertilizer application, plant protection products and soil liming (Shibalkin, 2020). Between 2015 and 2019, mineral fertilizers per hectare application increased by 25.2% to 56.2 kg in Russia (Table 1), while the application volume does not meet its

Table 1
Indicators of technological development of grain production in Russia, 2015–2019.

Indicators	2015	2016	2017	2018	2019	2019 to 2015, %
Mineral fertilizers applied per 1 ha, kg	44.9	50.73	50.6	52.9	56.2	125.2
Organic fertilizers applied per 1 ha, kg	652.7	655.5	647.0	631.1	643.2	98.5
Number of tractors per 1000 ha of arable land under cereals, units	3	3	3	3	3	100.0
Number of combine harvesters per 1000 ha of crops under grains, units	2	2	2	2	2	100.0
A load of arable land per 1 tractor, ha	308.0	320.0	328.0	337.0	345.0	112.0
Crop load per 1 harvester, ha	422.0	425.0	427.0	424.0	437.0	103.6
Limestone applied per 1 ha, tons	8.6	8.5	8.6	8.5	7.6	88.4
Gypsum applied per 1 ha, tons	2.8	4.2	4.9	5.0	6.2	221.4
Phosphate meal used per 1 ha	0.6	1.2	0.9	0.9	1.0	166.7
Energy intensity of labor, hp per person	74.0	77.0	75.0	80.0	83.0	112.2
Energy availability, hp per 100 ha	197.0	200.0	198.0	200.0	199.0	101.0
Share of machinery and equipment in fixed assets, %	36.8	37.5	37.4	38.4	38.5	104.6
Insecticide treatment per 1 ha, kg	0.5	0.5	0.5	0.5	0.5	109.3
Fungicide treatment per 1 ha, kg	1.4	1.3	1.34	1.3	1.3	91.2
Herbicide treatment per 1 ha, kg	0.9	1.1	1.05	1.1	1.1	120.0
Number of new technologies acquired, units	133.0	62.0	635.0	242.0	493.0	370.7
Number of highly productive jobs, thousand units	318.2	335.1	438.8	516.6	593.8	186.6

Source: Petukhova (2021).

normative value (less than 3–4 times the norm). The application of organic fertilizers per hectare decreased by 1.5% to 643.2 kg.

Farmers also use chemical reclamation in liming, gypsum or phosphate meal to improve soil fertility. During the five years under study, limestone application per hectare decreased by 11.6%, gypsum application increased by 2.2 times, phosphorite meal application increased by 66.7%. The volume of works on chemical melioration is insufficient, threatening soil degradation and its withdrawal from agricultural turnover.

The efficiency of fixed assets in grain production is determined by analyzing the indicators of the number of agricultural machinery per 1,000 hectares of crops or arable land and energy availability. Regarding these indicators, Russia significantly lags behind developed countries (the U.S. has 27 units, Germany has 83, Italy has 211). The tractors per 1,000 ha of arable land and combine harvesters per 1,000 ha of grain crops remained unchanged from 2015 to 2019, remaining at 3 and 2 units, respectively. This situation results in yield losses of up to 10–15%. The energy supply during the studied period has increased only by 1%, up to 199 horsepower (hp) per 100 ha, which is also an unfavorable factor in the technical and technological development of the sector. The share of machinery and equipment in the structure of fixed assets of crop farms was 38.5% in 2019, which is 4.6% higher than in 2015.

Labor productivity in grain production largely depends on the load of arable land per tractor, increasing annually. In 2019 this was 345 ha, and the load of crops per combine harvester increased (437 ha, +3.6%). At the same time, this figure is 37 ha in the U.S., 12 ha in Germany and 36 ha in China). High load rates on agricultural machinery with simultaneous wear and tear lead to frequent breakdowns and loss of part of the harvest.

Between 2015 and 2019, the sector significantly increased the number of new technologies acquired (3.7 times) to 493 units, which is quite low on a national scale. At the same time, the number of highly productive jobs increased by 86.6% to 593,800 (Petukhova, 2021).

In Russia, there is an increase in the innovation activity of farms in the form of growth of expenditures on technological innovation by more than six times in 5 years. The share of organizations implementing technological innovations in crop production has doubled, and the level of innovation activity of organizations engaged in crop production increased by 14.3% (Table 2). However, the indicators mentioned above are insufficient for a technological breakthrough in the sector (Paptsov, 2019).

The low technical and technological development level in the Russian crop sector leads to a shortfall in potential production. It also indicates unrealized opportunities to develop the sector through its scientific and technological advancement.

Thus, in the scientific and technological development of grain production, several problems do not facilitate a technological breakthrough in increasing the yield of grain crops and improving their quality.

1. The low level of innovation activity of agricultural producers, despite the positive dynamics of this indicator.

2. Inadequate application of mineral and organic fertilizers to cereal crops. These amounts are unable to compensate for the removal of nutrients from

Table 2
Indicators of scientific and technological development of crop production, including grain production in Russia, 2016–2019.

Indicators	2016	2017	2018	2019	2019 to 2016, %
Expenditures on technological innovations, million rubles	6276.1	8259.1	13 307.3	38 976.1	621.0
Share of organizations implementing technological innovations in crop production, %	3.7	6.2	5.2	7.5	202.7
Level of innovation activity of organizations engaged in crop production, %	4.2	4.2	4.0	4.8	114.3

Source: Petukhova (2021).

the soil and prevent chemical reclamation (liming, gypsum), leading to waterlogging, salinization and acidification of agricultural land.

3. Underdevelopment of seed market (about 30% of seeds sown are mass reproductions), the regulatory framework in the field of breeding and seed production, as well as lack of necessary linkage of business with science in the commercialization of crop varieties.

4. Shortage of highly qualified specialists able to work with modern information technologies in grain production, as well as of scientists in the field of agricultural sciences due to low levels of funding.

5. The high cost of grain crop production due to the predominant purchase of machinery, equipment and agrochemicals from abroad. High production costs may lead to a loss of competitiveness of Russian grain on the world market. It is especially relevant given the use of genetically modified organisms in the breeding of grain crops in many countries of the world, which reduces the cost of production by 30–40%.

Solving the problems mentioned above could provide a breakthrough in the scientific and technological development of grain production in Russia and realize the full potential available in the sector. Increasing innovation activity in the grain sector and the mass introduction of modern achievements of agricultural science, technology, and engineering could allow the most efficient use of all the factors in grain crop production (Cagnin, 2013).

Increasing innovation activity becomes especially relevant in the economy's transition to a new technological mode. However, scientific and technological progress in grain production is based not only on inherent economic laws but also on biological laws. It is necessary to apply an indicator that reflects all the scientific and technological progress elements in the industry (technical, natural and economic) to identify these patterns. Such an indicator that characterizes grain production's scientific and technological development is grain yield (Shibalkin, 2019). The grain yield is an integral indicator that combines information on the state of used machinery and equipment, the application of fertilizers, both organic and mineral, plant protection products, etc.

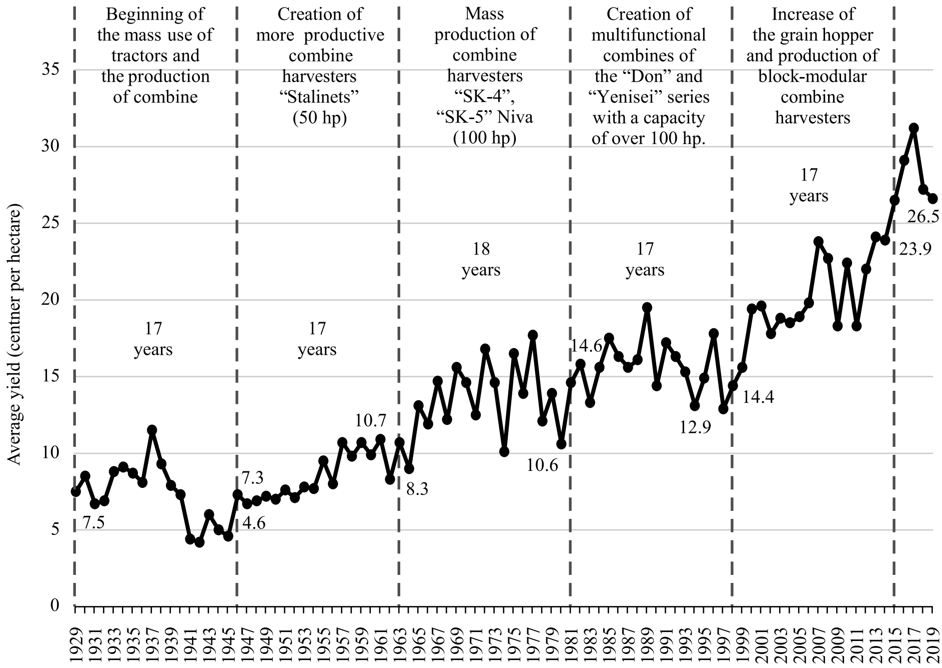

Fig. 1. Periodicity of scientific and technological development of the Russian grain sector in 1929–2019.

Source: Compiled by the author based on Kogan (1981) and statistics of the Russian Empire, the USSR and the Russian Federation.

Fig. 1 shows this periodicity from 1929 to 2019. The year 1929 saw a significant breakthrough in the production of agricultural machinery and the mass use of tractors in grain production. Therefore, this year was chosen as the starting point for this study. The beginning of each subsequent period is associated with the introduction of new machinery and technologies of cultivation and harvesting, which, accordingly, led to an increase in the yield, quality and volume of products.

The periodicity of grain production was determined by spectral analysis in Statistica software. The research results in 17-year periods (rounded value, the exact value is 16.3 years). One period (from 1963 to 1980) lasted 18 years. Five complete periods are identified, and the last one is the sixth period, which started in 2015 and has not yet ended.

The analysis has shown that periods of increased grain yields are associated with various advances in agricultural engineering, which have enabled increased machine power and productivity.

The beginning of the first period with a constant level of technological development coincides with the mass introduction of combines and tractors into crop production and the opening of the Rostselmash factory. The most used combine harvester was the Kommunar, which was hitched to a tractor. During this period, the average yield of grain crops in thee country was 7.3 centners per ha, with a maximum of 11.5 centners per ha in 1937.

The second period of development is the creation of the Stalinets combine harvesters. The combine harvesters became self-propelled with 53 hp, starting with the fourth model. This model could simultaneously cut, thresh, harvest and collect straw. The average grain yield from 1946 to 1962 was 8.5 centners per ha, with a maximum of 10.7 centners per ha in 1957, 1959 and 1961.

The beginning of the third period is associated with the creation of the SK series of combine harvesters by the Rostselmash factory, with increased throughput (4–5 kg per second) and power (up to 100 hp). The machines were able to work in different natural and climatic zones. Thanks to the introduction of these harvesters, the average grain yield increased to 13.4 centner per ha, while the maximum yield reached 17.7 centner per ha in 1977.

The fourth period with a constant level of technological development began with a sharp increase in grain yield by 37.7% to 14.6 quintals per hectare. The Don-1200 (160 hp) and Don-1500 (235 hp) harvesters entered grain production. These harvesters were modified for the non-chernozem zone, mountainous area, rice harvester, and caterpillar harvester). In this period, the average grain yield in Russia was 15.7 centners per hectare, while the maximum yield was 19.5 centners per ha in 1989. At the same time, labor productivity in the sector decreased by 17.5% compared to the previous period to 8,500 tons per person.

The fifth period is characterized by using the highly productive Acros and Vector harvesters in crop production. This period began in 1998 with the recovery from adverse weather conditions and the economic crisis. These multifunctional machines are designed for the harvesting of both kinds of cereal and leguminous and oilseed crops. The power of the first model, Acros 530, was 255 hp, and one of the latest Acros 590 Plus was 325 hp. During this period, the average yield of grain rose by 27% compared with the previous one and amounted to 19.9 centners per hectare. The maximum yield was 23.8 centners per hectare in 2007. Labor productivity increased significantly by 2.4 times to 20,300 tons per ha.

The sixth period saw a technological leap forward in harvesting crops with the help of powerful, high-performance combine harvesters equipped with elements of precision farming technology (RSM series, Torum). The sixth period is now underway. Their power comes up to 500 hp. In recent years, unmanned vehicles, which significantly reduce crop losses and are resource-efficient, have appeared. Between 2015 and 2020, the average grain yield was 28.2 quintals per hectare, and productivity was 23,600 tons per person (USDA, 2021).

Of course, it cannot be said that the increase in grain yields was solely due to the use of new harvesters and tractors. The use of machinery was only one factor. The scientific and technological development of the sector also took place through the use of recent breeding achievements, mineral fertilizers, tillage methods, etc. The influence of the natural-climatic factor on the value of grain yield is weaker than the influence of technical-technological factors.

Each of the highlighted periods is characterized by a critical factor of production, i.e., the factor that has had the most significant impact on crop yields. At present, in the developed countries (EU, U.S.), this factor is labor in the form of human capital, which is represented as a set of knowledge, skills and abilities of agricultural production workers. In Russia today, land is still a critical factor of production (Sayer, 2013).

Table 3
Indicators of scientific and technological development of grain production in Russia, 1963–2014.

Year	Gross grain harvest, million tons	Labor productivity, thousand tons per person	Capital productivity, tons per thousand rubles	Yield, centners per ha
1963	86.8	8.0	2181.0	10.7
1964	87.0	10.6	3099.2	9.0
1965	69.7	8.0	2171.0	13.1
1966	99.9	11.2	2978.5	11.9
1967	89.5	10.1	3206.6	14.7
1968	109.6	12.3	3636.7	12.2
1969	89.9	10.0	2732.0	15.6
1970	113.5	12.1	3109.7	14.6
1971	104.8	11.0	2556.2	12.5
1972	91.6	9.5	1973.6	16.8
1973	129.0	13.1	2326.9	14.6
1974	111.8	11.1	1794.3	10.1
1975	77.5	7.4	1127.2	16.5
1976	127.1	11.8	1693.8	13.9
1977	108.7	9.9	1324.0	17.7
1978	136.5	12.1	1499.5	12.1
1979	91.9	8.1	943.4	13.9
1980	105.0	9.0	511.4	10.6
1981	73.8	6.3	626.1	14.6
1982	98.0	7.8	800.5	15.8
1983	104.3	8.4	796.3	13.3
1984	85.1	6.9	672.4	15.6
1985	98.6	8.1	732.1	17.5
1986	107.5	8.9	689.3	16.3
1987	98.6	8.2	597.9	15.6
1988	93.7	7.9	541.0	16.1
1989	104.8	8.9	575.1	19.5
1990	116.7	11.7	606.9	14.4
1991	89.1	8.9	424.4	17.2
1992	106.9	10.3	448.2	16.3
1993	99.1	9.6	412.7	15.3
1994	81.3	8.3	377.1	13.1
1995	63.4	6.5	341.6	14.9
1996	69.3	7.5	407.5	17.8
1997	88.6	10.3	564.6	12.9
1998	47.9	5.5	322.7	14.4
1999	54.7	12.4	43.0	15.6
2000	65.5	15.0	58.6	19.4
2001	85.1	20.6	72.7	19.6
2002	86.5	21.7	73.1	17.8
2003	67.0	17.9	56.5	18.8
2004	77.8	21.7	55.7	18.5
2005	77.8	20.0	54.0	18.9
2006	78.2	20.7	49.7	19.8
2007	81.5	22.2	41.5	23.8
2008	108.2	30.7	47.9	22.7
2009	97.1	27.9	37.8	18.3
2010	61.0	17.7	21.3	22.4
2011	94.2	27.6	30.1	18.3
2012	70.9	21.1	21.2	22.0
2013	92.4	27.9	25.2	24.1
2014	103.8	16.6	26.6	23.9

Source: Authors’ calculations.

Production functions were constructed to identify the key factor (Rudoy, 2020), where: Y — gross grain harvest; L — labor productivity; K — fund productivity; S — yield. Table 3 presents the data for the construction of the functions.

Models of the production function are constructed for each of the periods. The model is as follows for the period 1963–1980:

$$Y = 17.1\,L^{1.3}K^{-0.2}S^{0.17}.$$

Period 1981–1997:

$$Y = 1.09\,L^{0.76}K^{0.3}S^{0.26}.$$

Period 1998–2014:

$$Y = 2.7\,L^{0.5}K^{0.13}S^{0.5}.$$

The coefficients of determination for the equations are 0.98, 0.85 and 0.74, respectively, indicating the constructed models' reliability and validity.

Let us look at each of the periods in more detail. Between 1963 and 1980, labor in the form of productivity was the key factor. A 1% increase in labor productivity during this period led to a 130% increase in gross yield. Fixed assets and land were used inefficiently. According to the Table 3, by the middle of this period, labor productivity in grain production reached its maximum value of 13,100 tons per person, after which it started to decrease.

Between 1981 and 1997, labor was also a key factor. However, the contribution of labor productivity to the increase in the gross grain harvest declined. Efficiency in the use of fixed capital increased, as did land. Also, according to the Table 3, the main factors of grain production were used efficiently during this period. And by the middle of the period, a maximum value of labor productivity of 11,700 tons per person was reached, after which it declines.

The period from 1998 to 2014 is characterized by a gradual decline in the contribution of labor productivity to gross grain yield growth. The result of the period is an equal ratio in terms of elasticity coefficient to yield. In contrast, the impact of yields is gradually increasing. By 2008, the maximum labor productivity in the sector reached 30,700 tons per person, followed by a decrease.

Today, the available resources tend to reduce labor productivity by increasing the gross harvest of grain and increasing the impact of yields. These resources need to be directed towards increasing the efficiency of agricultural land outcomes (expanding the application of mineral and organic fertilizers, plant protection products and improving the quality of seeds, etc.).

The scientific and technological development of grain production in Russia has lagged behind developed countries, where land was critical in yields during the Green Revolution. The Green Revolution envisaged a significant increase in crop yields through new breeding methods, fertilizer application and the use of crop protection products.

In Russia, however, due to the collapse of the Soviet Union, the Green Revolution has not developed correctly (the quality of seed has deteriorated, the application of mineral fertilizers has decreased, etc.). On the one hand, the underdevelopment of the Green Revolution did not allow the full potential of grain crops to be realized. On the other hand, it prevented the catastrophic pollution of soils with chemicals, which happened in many countries. Therefore, a Second Green Revolution is now needed, which will increase grain yields without harming the environment. The key factor determines the directions of scientific and technological development of grain production in a certain period. In the period that began in 2015, the priority areas of research and development will have to ensure the growth of efficiency of the factor "land." These include:

- Biotechnologies of effective accelerated breeding and intensive technologies in seed production;
- Precision farming technologies;
- Technologies of biological and organic farming;
- Improved phytoreclamation technologies (Rudoy, 2020).

The use of these technologies will, on the one hand, unlock the full potential of Russia's soils and crops and, on the other hand, will not lead to the contamination of ecosystems.

A key factor in Russia's grain sector will be labor in the form of human capital in the following scientific and technological order period. Human capital is the body of knowledge, skills and abilities of workers in the sector aimed at increasing productivity. Technologies of this period include digital technologies based on extensive data analysis and robots.

5. Conclusions

The article attempts to identify and formulate the regularities in the scientific and technological development of the grain sector in Russia. Five periods of about 17 years have been identified by analyzing the dynamics of the grain yield indicator. In these periods, the yield has increased significantly up to the local maximum due to the improvement of grain harvesting equipment. Also, in each period, the critical grain production factor that had the most significant impact on the gross yield was identified in the most recent period, which began in 2015.

It is worth noting that land was a critical factor in the previous period of the Green Revolution in the U.S. and most EU countries. Now the critical factor is human capital. Russia is lagging behind the developed world in the transition to new technological modes. This transition is both a challenge and a window of opportunity. The use of mineral fertilizers and agrochemicals in Russia is minimal, unlike in many countries. This situation opens up new markets for Russia in high-margin and export-oriented organic products. Therefore, the promising directions of scientific and technological development of the grain sector in the long term will be technologies that fully unlock the potential of soils and crops without harming ecosystems.

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