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DEVELOPMENT OF A MATRIX OF FOOD INDUSTRY CAPACITY FOR MAKING MANAGEMENT DECISIONS IN THE FORMATION OF SUSTAINABLE DEVELOPMENT OF AGROECOSYSTEMS

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A theoretical and methodological study was carried out to determine the need and features of developing a matrix of food industry capacity for making management decisions in the formation of sustainable development of agroecosystems, which will increase the operational efficiency of companies and food security of the country. The paper uses the following research methods: historical – in the process of studying modern views on understanding the importance of the agricultural sector for the economy; system analysis – when building a model of innovative business improvement. Methods of comparison and analysis of trends – the study of trends in the agricultural sector of Ukraine with the identification of important areas for improving their activities. Methods of financial analysis – for the analytical assessment of financial and economic activities of the investigated enterprises; forecasting methods – to substantiate the expected results of implementing the author's proposals in management practice. It is proposed to take into account the significant difference in the technology of their processing and production (number of advanced technologies used per 100 thousand people). The paper reveals the dependence of production technologies in agriculture on natural and weather conditions (share of technological innovation costs, %). Criteria for innovation skills in the development of agricultural engineering were proposed. The criteria were determined, which were divided into development groups. The tools for constructing a matrix of food industry capacity were substantiated. Note that for each indicator, the optimal value was determined taking into account the sensitivity factor and the rating of enterprises, which determined their place in the matrix. In the course of the study and the matrix of innovative development, the proposed technology was tested at leading domestic enterprises

Keywords: digitalization, technological transformation, customization, high-tech agriculture, food security

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1. Introduction

The growth of the world's population, which most experts consider inevitable (according to the United Nations, by 2030 the planet will be inhabited by 8.6 billion people and by 2050 almost 10 billion), is due to increased fertility, urbanization, migration.

In addition, an increase in the average level of welfare (expected GDP growth per capita will average 40–50 % by 2030–2035) is a powerful driver of increasing food demand (by 2050 it will grow by 60–70 % compared to 2,000) [1]. However, the demand itself is very inhomogeneous. In particular, fast-growing niches of functional and eco-products are highlighted: the market for functional products will amount to $305 billion by 2020 with an annual growth rate of about 8.5 %. Traditional products (such as meat) may lose their place due to a sharp decline in the cost of substitutes. For example, the cost of synthetic meat has dropped from more than $300 thousand to $3–$10 per cutlet over the past five years, that is, more than 30 thousand times. In 2013, the first cultured-meat burger was made. Within 10 years, by 2030, manufacturers promise a price of $5 per kg of such meat. Also, genetically modified salmon (AquaBounty, which gains weight much faster) can become a real competitor to the traditional one. Although we should not ignore the fact of ambiguous attitudes of state regulators and public organizations in the United States and Canada to such technologies. Consumers who are willing to take care of nature and want to customize products to their needs, "vote with rubles", challenging the sovereignty of the manufacturer as the main manager of tastes and preferences.

Artificial intelligence is introduced in the agroecosystem primarily to eliminate human labor in routine agricultural processes (Fig. 1). It will also provide automatic identification, diagnosis and classification of diseased and healthy plants.

Moreover, in agriculture, people can return to traditional, but half-forgotten and replaced by Europeans crops, such as quinoa and millet, grown in the highlands, which were characterized by increased resistance and unpretentiousness [4]. Protein-rich quinoa is considered one of the main products of the 21st century, but seaweed, which already occupies a key place in the diet of Asian countries, can compete with cereals.

Livestock accounts for almost 20 % of global carbon emissions, which is more than transport [5]. However, this figure should decrease in the future due to the widespread use of renewable energy sources. It is wind farms and solar panels installed in rural areas that will power swarms of agricultural robots. Also, using new mineral-based batteries will reduce the cost of solar energy by 75 % and thus reduce production costs.

In the middle of the XXI century, the world's population will be at least 9 billion people. Three-quarters of them will live in cities, so it makes sense to save on transport and transfer high-tech agriculture to megacities [6]. This will be possible using vertical farms: they do not require large areas and allow harvesting all year round. According to the Canadian government's forecast, such agricultural complexes will become the norm by 2027, while experimental farms exist in the yards and on the roofs of residential and administrative buildings. The Japanese company Pasona has implemented one of the most famous examples of a vertical garden. Much of the organization's headquarter was given to hydroponic plants and artificial beds to grow rice, vegetables and fruits for workers [7].

Despite the above-mentioned innovations, traditional agriculture may still not be able to cope with consumption, which will double by 2050. However, scientists are already looking for alternatives. In August 2019 in London, two volunteers tried the first artificial hamburger grown from induced stem cells in a laboratory. Google co-founder Serhyi Brin bought a cutlet for about $400 thousand but it appeared hard and soft. This is normal: if the research sponsored by him continues, by 2025 artificial meat will become tastier, cheaper and can replace real meat. Moreover, it is not just a whim: the livestock system in its current form is unstable and inefficient, up to a third of the world's land is used for grazing, and farm animals consume most of the grain grown [9]. Not only Serhiy Brin realizes this. Bill Gates has invested in experiments to grow meat from stem cells, and Twitter co-founders Biz Stone and Evan Williams suggest using artificial substitutes based on plant materials.

Fig. 1. Demand for food will grow by 70 % by 2050 [3]

Such food is affordable and easier to produce than conventional animal husbandry and causes less harm to the environment. It should also be borne in mind that at least one billion people in developing countries already consume several thousand species of insects (the European Union has invested $4 million in such research). The need of food manufacturers for technological transformation is a challenge of today, otherwise, they may irretrievably lag behind and lose market position. But before implementing the solution, it is necessary to determine the components and innovation drivers and criteria for the development of modern agricultural engineering.

2. Literature review and problem statement

The paper [10] presents the results of research, where the authors identified the prospects for the technological transformation of the food industry based on providing agriculture with a material and technical base, processing industry and agriculture itself. But the issues of hunger eradication remained unresolved, which were later developed in the context of the "concept of sustainable development" in [11] through global food trade. This approach is widely discussed and considered in international forums as a component in shaping global sustainable development. However, changes in recent years have led many researchers to argue that a new phase of digitalization is beginning, which requires adaptation and ensuring food security. The MIT Technology Review called precision farming one of the breakthroughs: with the advent of technological capabilities for analyzing big data, one of the vital sectors of the economy simply cannot remain unchanged. The principle of precision farming is based on the idea that the cultivated area is not homogeneous, and each individual plot requires unique care [12]. In practice, this minimizes costs: using ground-based sensors, as well as satellite and aerial photography, fertilizers can be applied only where needed. According to the Canadian government's forecast, by 2020, agricultural drones and sensors monitoring the condition of soil, air and crops in the fields will become the norm. In the future, using the information received from them, intelligent systems will be able to decide on plant care without involving people. A similar trend is expected in animal husbandry: thanks to sensors, farmers will be able to obtain information about the welfare of each animal in real time. In the future, the food problem may require finding new food sources. Therefore, for the next 20 years, humanity was forced to use insects for food to defeat hunger, according to the UN [13]. Talking about the hypothesis of stability of the agricultural sector, the idea was first published in 1798. In [14], the author drew attention to a possible unlimited population growth, which may surpass the ability of mankind to produce food, leading to famine and war. This did not happen at the beginning of the 21st century, as our growing need for food was met by technical development. This has led to another problem, namely environmental, so productivity (food production methods) is becoming an increasingly important aspect [15].

Various factors can affect the choice of tool. The authors [16] note that the characteristics at the level of an agricultural enterprise (farm) relate to the use of data as a target group. It is shown that the current choice of the tool for assessing the stability of an agricultural enterprise as a system depends on data, time and budget constraints. To address this issue, the authors in [17, 18] have developed various tools for determining the sustainability of agroecosystems for the transition to sustainable production. This approach was used in [19], where the authors proposed tools for measuring and monitoring the sustainability of agricultural enterprises. It is shown that the tools can be distributed by geographical and sectoral coverage, target groups, policies, while aggregation methods have not been taken into account. In some papers [20, 21], the authors emphasize the importance of integrating environmental, economic and social topics into sustainability measurement tools, but more attention is paid to environmental topics and tools.

The work [22] shows that to determine food security, state authorities need accurate, transparent information from agricultural enterprises on the introduction of technology, land degradation, using fertilizers and pesticides. However, the issues related to the availability of loans and technologies to agricultural enterprises, state regulation of food prices, crop losses from natural disasters and post-harvest waste remained unresolved.

An option to overcome the relevant difficulties may be to assess the sustainability of agricultural enterprises. [23] presents tools and structures used in assessing the sustainability of agricultural enterprises designed to support decision-making in the agricultural sector. However, the issue of considering integrated indicators used at the global level to measure and monitor agricultural sustainability in different countries remained unresolved. Moreover, being context-sensitive, these tools and platforms do not provide a reliable basis for comparing countries in terms of sustainability of the agricultural sector. Therefore, it is recommended to introduce a set of indicators that allow countries to assess the sustainability of their own agricultural sector, build a matrix of food industry capacity and compare their status with other countries. Such sets of indicators should be cost-effective and countries with different agricultural systems, such as agriculture and animal husbandry, should be able to apply them.

In [24], the authors determined the relationship between growing global competition and technological development and rapid changes in consumer demand, but did not pay attention to the relationship between the productivity of food enterprises and continuous improvement and introduction of new technologies. The works [25, 26] show that food enterprises rely on external sources of information to choose the introduction of technological innovations, without taking into account and highlighting the features of their own enterprise. That is, no special attention is paid to the quality of human resources, geographical context and age of the enterprise. Much research has focused on the study of product and process innovations, while identifying and building a matrix of food industry capacity have been overlooked.

The review confirmed the importance of the technological transformation of the food industry to ensure the country's food security. At the same time, there is a clash of researchers' opinions regarding options for such provision. In the context of the literature review, the components and innovation drivers of the development of modern agricultural engineering need to be revised. Thus, the lack of objectively defined criteria of innovation skills and the principles of creating a roadmap for the improved development of the food industry complicate the technological transformation of the food industry. The issue of developing a capacity matrix as a sound system of indicators for sustainable development of food enterprises remains unanswered, which proves the need for appropriate research.

3. The aim and objectives of the study

The aim of the study is to develop a matrix of food industry capacity for making management decisions to increase the sustainability of the technological transformation of the food industry in the formation of sustainable development of agroecosystems.

To achieve the aim, the following objectives were set:

– to identify the components and innovation drivers for the development of modern agricultural engineering;

– to offer criteria of innovation skills in the development of agricultural engineering;

– to determine the principles of creating a roadmap for the improved development of the food industry.

4. Materials and methods of the study

In the process of the study, reporting and analytical information and information base were used [10–26]. For the study, the dialectical method was used to identify contradictions in the methodological approaches to determining the features of the technological transformation of the food industry, based on providing agriculture with a material and technical base. Based on the system-structural method on the principle of systematic research of socio-economic phenomena and processes, the components of the process of innovative development of modern agricultural engineering were identified. Using the historical-logical method, innovation drivers for the development of agricultural engineering were singled out.

Based on the methods of quantitative and qualitative comparison, observation during the consideration of patterns, comparing the state and structure of indicators, the production dynamics of agricultural engineering and its purchase by agricultural enterprises for production needs were determined.

5. Results of determining the features of making management decisions to increase the sustainability of the technological transformation of the food industry to build a matrix of food industry capacity

5. 1. Components and innovation drivers of development in modern agricultural engineering

It is proposed to refer the set of types of agricultural products and processing products to the main components of innovative development of modern agricultural engineering (Fig. 2). The significant difference in their processing and production technologies, the strong dependence of production technologies in agriculture on natural and weather conditions, the large difference in the production period for certain types of agricultural products and processing products should be taken into account. It is proposed to focus on the high degree of geographical separation of agricultural production, the separation of agricultural producers (at all levels) from organizations producing scientific and technical products, different social levels of agricultural workers.

Undoubtedly, during the study of factors influencing the innovative development of agricultural engineering, the specifics of this industry were studied. Accordingly, knowing the specifics and influencing factors, it is possible to choose a set of measures to intensify the formation and introduction of innovations for the development of the national industrial complex [27]. In order to objectively identify the key factors of the development of innovation processes in engineering, a list of indicators was formed during the study. It is noted that the formed list of indicators will allow assessing the state of the industry not only qualitatively, but also quantitatively, which will allow describing in detail the development prospects and outlining problematic aspects. It is noted that the grouping of innovation drivers for the development of modern agricultural engineering is aimed at implementing measures to ensure sustainable development of agroecosystems. Implementation of measures is possible through the introduction of highly efficient machinery and equipment of own production, which is a stimulating factor to increase the presence of national manufacturers in the national and international markets (Fig. 3).

To objectively identify the key factors of development of innovation processes in agricultural engineering, a list of indicators that allow assessing the state of the industry qualitatively and quantitatively and solving problems was formed during the study.

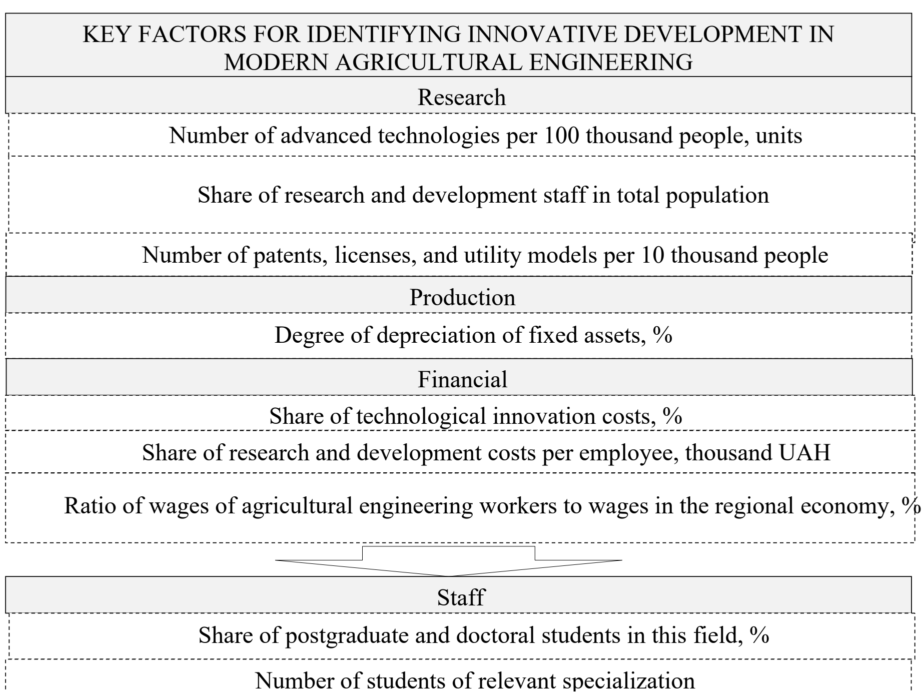

Fig. 2. Components of innovative development of modern agricultural engineering

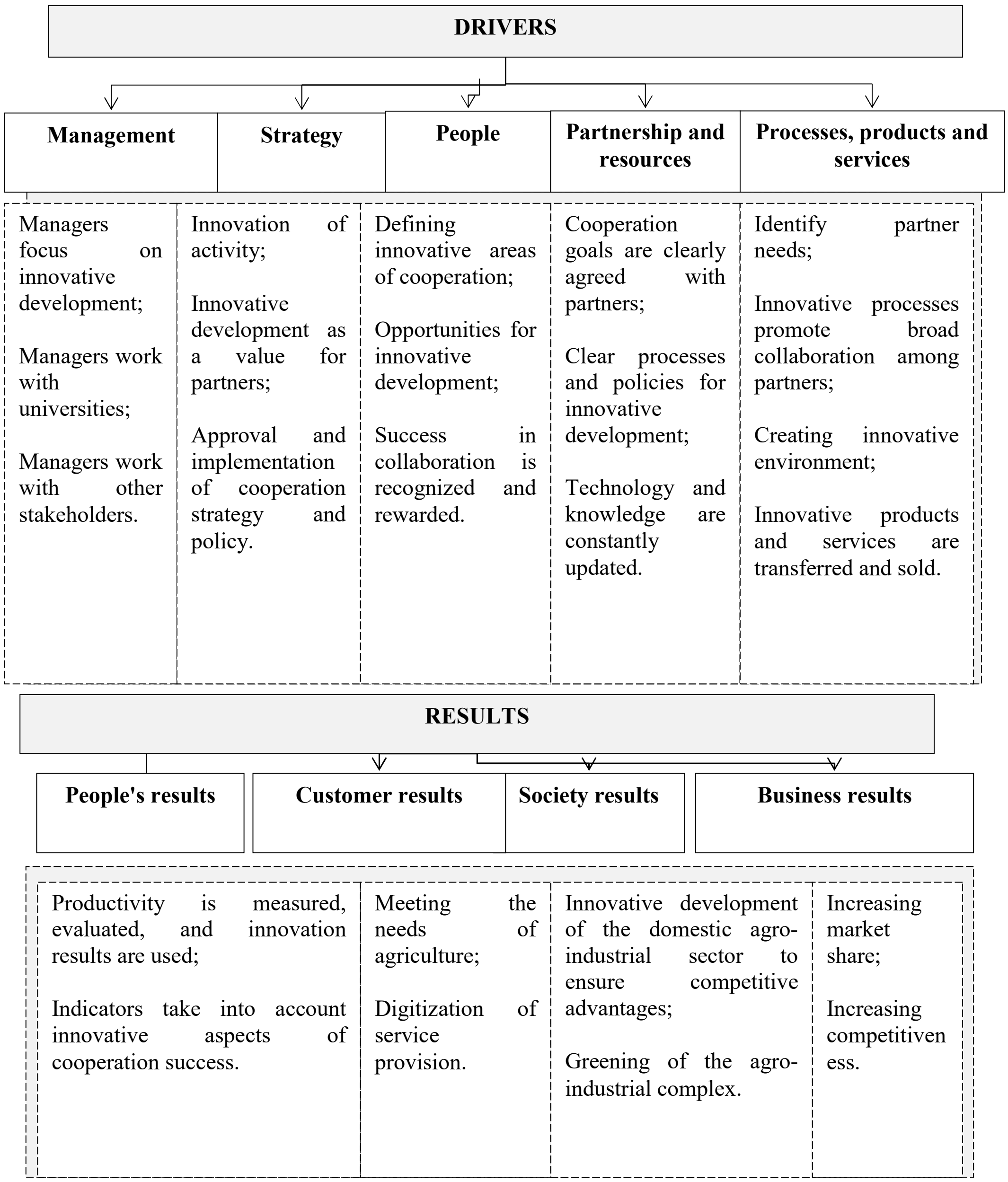

Fig. 3. Innovation driver of agricultural engineering development

5. 2. Criteria of innovation skills in the development of agricultural engineering

Analyzing the data of Fig. 1, it is expedient to form criteria of innovation skills (Table 1), which are adapted to the management of innovative development of agricultural engineering.

Using the criteria of innovation skills (a_{ij}), where the rows contain the numbers of indicators (i=1, 2, 3, ..., n), and the columns – the names of the enterprises under consideration (j=1, 2, 3, ..., m), for each indicator we determine the values taking into account the sensitivity factor (k) and the rating of enterprises, determining their place in the rating.

Table 1

Criteria of innovation skills in the development of agricultural engineering*

(1)	Research manager – Innovations in agricultural engineering Managers recognize the importance of innovation in developing the organization's mission and vision Managers interact with customers, partners and society Managers are involved in scientific research – collaboration in agricultural engineering
(2)	Scientific strategy – Innovations in agricultural engineering Innovations are integrated into the organization's strategy, considering the needs and expectations of stakeholders Innovation goals and strategy are based on an understanding of internal activities and opportunities Innovation strategy and drivers of innovative development are developed, revised and updated Innovation strategy and tactics are transferred and applied through plans, processes and goals

Continuation of Table 1

(3)	Persons involved in research – Innovations in agricultural engineering Roles and responsibilities are clearly defined to support innovation goals Knowledge and capabilities of employees needed to succeed in innovation are recognized and developed Persons involved communicate effectively within their organization and during cooperation Employees are rewarded and recognized for success in cooperation
(4)	Partnership and relevant resources – Innovations in agricultural engineering Management of university-industry partnerships is carried out on a mutually beneficial basis by supporting broad partnerships Attracting funding for innovation ensures stable success Technological complementarity supports cooperation and collaboration Information and knowledge, including intellectual property, enable effective innovations
(5)	Relevant processes, products and services – Innovations in agricultural engineering Developed processes, products and services provide value for both the university and industry Actively manage innovation projects Products and services are effectively promoted and sold
(6)	Research results – Innovations in agricultural engineering Performance indicators and cooperation goals are determined Different measures of success are taken into account in indicators and goals Performance indicators and goals are actively managed and used

The sensitivity factor (K) can be calculated from the ratio

$$K = \overline{f(n)}\left(\overline{x} / \overline{y}\right), \tag{1}$$

where $\overline{f(n)}$ is the average value of the derivative of the multifactor approximating function by the argument $\overline{x}$ in the time interval; $\overline{x}$ and $\overline{y}$ are the sample averages of the factor x and the forecast value of the enterprise stability factor y, respectively.

Thus, the quantitative assessment of the sensitivity of agricultural engineering enterprises can be determined by calculating the sensitivity factors as a result of constructing a regression equation to assess the degree of influence of external factors on changes in the main indicators of the enterprise's production and economic activity.

For each indicator, the best value is determined and enterprises are ranked with the definition of their place.

For each enterprise, the sum of places (P_j) received during rating is determined by the formula:

$$P_j = \sum_{i=1}^{n} a_{ij} * k, \tag{2}$$

P_j – sum of rating places for each company; a_{ij} – criteria of innovation skills; k – sensitivity factor.

After finding the sum of places (P_j) received during the rating for each company, they are converted into the length of the scalar (2). The length of the scalar that creates the square of the enterprise capacity (B_k, where k – 1, 2, ...) is found by the formula:

$$B_k = 100 - \left(P_j - \sum k \cdot n\right)\frac{100}{\sum k \cdot n(m-1)}, \tag{3}$$

where B_k is the value of the scalar characterizing the k-section; P_j is the sum of places; j is the enterprise in the k-section, obtained during the rating; n is the number of rating indicators in the k-section; m is the number of enterprises under study.

Thus, the definition of criteria for innovation skills in the development of agricultural engineering will provide information on the average level of competitive opportunities for each enterprise in this industry.

The calculation of the final rating is based on comparing enterprises by each indicator according to certain criteria of innovation skills in the development of agricultural engineering with a real enterprise that has the best results on the market. Thus, the basis for rating the state and level of management of innovative development of agricultural engineering is not the subjective opinions of experts, inherent in most other assessment methods, but the most objective results achieved in real competition.

Innovation skills in the development of agricultural engineering can be classified by size into large, medium and small. Enterprises have large capacity when the length of the scalars is within 70–100; medium – 30–70; small – up to 30 conventional units. This approach corresponds to the practice of market competition, where each independent producer tries to be better than its competitor in all indicators.

By focusing on strengths and taking measures to eliminate bottlenecks in the food industry, given opportunities and threats, their effective technological transformation and ability to function effectively in a changing market environment in the future can be ensured. When determining the size of the scalar *Bk*, the objective result may be an increase in the efficiency of the technological transformation of the food industry.

In the current market situation, leading agricultural enterprises see digital tools as reserves for increasing productivity and savings in production. Many individual elements of digital agriculture are active. One of such relevant elements is equipment monitoring. This is tested in practice by many agricultural enterprises. However, monitoring services on the market are designed to perform a control and accounting function, recording labor and time costs [28]. However, monitoring of technologies as a separate element of digital agriculture does not 100 % reveal the capacity for effective use of modern technologies, it should be integrated with agronomy (Table 2).

Analyzing the market, it should be noted that the agricultural industry maintains a high level of consumption of traditional products. Demand for products can be limited only by economic variability, declining purchasing power and rising prices. Enterprises have almost tangential scalars to ensure business excellence, but there is a limiting factor in milk and dairy production. Their markets are low-quality raw materials due to unfavorable trends in the Ukrainian livestock sector, as evidenced by their capacity. But issues remain unresolved due to the fact that few farmers seriously use tools such as agricultural exploration. Also, precision farming is not used, which provides for a whole set of digitization elements during implementation, from processing and analysis of satellite images to mapping yields.

Fig. 4. Square of the capacity of food industry enterprises according to the criteria of innovation skills in the development of agricultural engineering: *a* – research manager – innovations in agricultural engineering;
b – scientific strategy – innovations in agricultural engineering;
c – relevant processes, products and services – innovations in agricultural engineering;
d – persons involved in research – innovations in agricultural engineering;
e – partnership and relevant resources – Innovations in agricultural engineering;
f – research results – innovations in agricultural engineering

Table 2

Matrix of Ukraine's food industry capacity

Standard	Enterprise	P_j	B_{k1}	Standard	Enterprise	P_j	B_{k2}
1	2	3	4	5	6	7	8
Research manager – Innovations in agricultural engineering	Mironivsky hliboproduct	11.25	91.88	Persons involved in research – Innovations in agricultural engineering	Mironivsky hliboproduct	11.7	86.57
	Globino	15.95	80.13		Globino	10.45	90.14
	APK-Invest	34.1	34.75		APK-Invest	30.6	32.57
	Danone	30.85	42.88		Danone	27.75	40.71
	Lustdorf	33.2	37		Lustdorf	26.8	43.42
	Galychyna-Dubnomoloko	36.15	29.63		Galychyna-Dubnomoloko	39.7	6.57
Standard	Enterprise	P_j	B_{k3}	Standard	Enterprise	P_j	B_{k4}
Scientific strategy – Innovations in agricultural engineering	Mironivsky hliboproduct	17.2	70.86	Partnership and relevant resources – Innovations in agricultural engineering	Mironivsky hliboproduct	19.85	89.46
	Globino	20.65	61		Globino	32.5	70
	APK-Invest	19.9	63.14		APK-Invest	55.2	35.07
	Danone	29.25	36.43		Danone	58.45	30.07
	Lustdorf	28.1	39.71		Lustdorf	41.1	56.77
	Galychyna-Dubnomoloko	31.9	28.86		Galychyna-Dubnomoloko	65.9	18.61
Standard	Enterprise	P_j	B_{k5}	Standard	Enterprise	P_j	B_{k6}
Relevant processt-es, products and services – Innovations in agricultural engineering	Mironivsky hliboproduct	16,3	69,52	Research results – Innovations in agricultural engineering	Mironivsky hliboproduct	12,3	86,48
	Globino	19.65	61.3		Globino	11.25	89.18
	APK-Invest	18.98	62.4		APK-Invest	30.6	33.75
	Danone	28.85	35.86		Danone	27.75	41.25
	Lustdorf	27.9	40.45		Lustdorf	26.8	44.22
	Galychyna-Dubnomoloko	32.2	29.81		Galychyna-Dubnomoloko	39.7	12.65

The introduction of innovative technologies in the field during the growing season would help track crops associated with the risks of pest and disease damage. Today, the market offers a large number of innovative technologies in agricultural engineering. In particular, the promotion of satellite field monitoring should be noted. Today, it is the most accessible and widespread tool in terms of daily monitoring of the territory for timely detection of problems in the field and making prompt decisions to minimize crop loss [29]. However, there are two important parameters to consider, image resolution and frequency. Only high-resolution images where you can detect changes in the field will be useful, not individual blurred pixels. The frequency of shots is also important.

5. 3. Principles of creating a roadmap for improved development of the food industry

The introduction of digital technologies in the agricultural sector is hampered by a number of reasons, one of which, and perhaps the main one, is the level of software solutions that are currently provided by many companies. Agricultural producers do not need individual elements of technology, but a comprehensive solution that is provided by only a few companies in the world, which employ a large number of IT specialists, as well as agronomists and engineers.

In addition, on the part of agricultural producers, of course, this is the level of development of the machine and tractor fleet, lack of funds, simply lack of equipment and personnel issues. Sometimes it is necessary to do a double job, because the existing system of data collection and integration is incompatible with another. The stimulating factor here is the interest of farmers in bringing their production to a new level of efficiency and organization.

The state is interested in the introduction of digital technologies in the agricultural sector. After all, stimulating the introduction of digital technologies will increase the number and quality of products of the Ukrainian agricultural sector. Sufficient quality products will help to feed people, as well as increase the profitability of agricultural production and strengthen the stability and sustainable development of agriculture. However, it is important to understand that digitalization in the context of a particular agricultural enterprise should not be artificially stimulated from the outside by the state, but should occur organically with all other functioning mechanisms being fully established [30].

In order to improve the management of the technological transformation of the food industry in the formation of sustainable development of agroecosystems, digital agriculture is introduced. It should be borne in mind that it is a fundamentally new management strategy based on the use of digital technologies, and a new stage in the development of the agricultural sector, associated with the use of geographic information systems. It is also necessary to take into account the global positioning of enterprises, on-board computers and smart equipment, as well as management and execution processes that can differentiate between the methods of treatment, fertilizing, chemical reclamation and plant protection. Digitalization of the agro-ecosystem will also positively affect the digitalization of rural infrastructure, in particular with regard to connecting villages to high-speed Internet. The low level of rural economic development leads to the migration of rural youth to cities, high unemployment and low incomes of the rural population, the destruction of social and engineering infrastructure and so on. That is why the agro-industrial business is interested in using information technology both in the field and at home to improve the quality of life in rural areas and achieve higher social standards. The agricultural sector will have to solve a whole set of various problems: from digital transformation and reducing logistics losses to the search for new markets and multiple expansion of export capacity.

An additional incentive for enterprises and the state should be the implementation of national projects, the roadmaps for which set very ambitious goals: from the export of agricultural products worth $45 billion, starting in 2024, to increasing the share of innovative companies to 50 %. The way out of this situation can be the development of a system of scientific and technical forecasting and planning, which can be implemented not only at the level of the whole industry, but also in one company (Fig. 5).

The system consists of five blocks.

The first – forecasting – allows forming the image of the future agro-industrial complex on the basis of scientifically based methods – expert surveys, for example, as in Japan or South Korea, the Delphi method (two-stage large-scale survey of at least 300–500 experts), scenario models, as in EU countries, and big data, the analysis of which, however, applies to all elements of the system [31]. Technologies of implementation detail the selected priorities within the third block – a system of technological roadmaps that clearly reflect the routes to the goals, threats and risks in achieving them. After answering the questions "what to develop" and "how to move", it is necessary to choose an effective set of implementation tools, formed on the principle of the investment portfolio, when each task has its own set of optimal measures [32]. Finally, companies often forget about the fifth integral element of the system, as well as the capabilities and effectiveness of selected funds – constant monitoring of global problems associated with them. Only following future changes, it is possible to effectively manage the existing portfolio of agro-industrial projects and lay solid foundations for future expansion.

6. Discussion of the assessment of the impact of research trends on the progressive decline in the agricultural sector and building a matrix of food industry capacity

In recent years, some work has been done to reform agriculture, in particular, to increase the sustainability of the technological transformation of the food industry in the formation of sustainable development of agroecosystems. Work is underway to strengthen the legal framework of relations between entities producing, processing and selling agricultural products, attract investments in the industry, introduce resource-saving technologies, as well as provide agricultural producers with modern equipment [33]. At the same time, the lack of a matrix of food industry capacity for making management decisions hinders the efficient use of land and water resources, wide investment in the industry, generation of high-incomes and improvement of product competitiveness.

In order to diversify the transformation of the food industry, create a favorable agribusiness climate and high value-added chain, support the development of cooperation, widespread introduction of market mechanisms and information and communication technologies, components and innovation drivers of development in modern agricultural engineering are identified (Fig. 2). Identification of elements and innovation drivers of development in modern agricultural engineering will ensure the implementation of projects aimed at achieving technical characteristics and overcoming technological barriers identified in the roadmap.

Identification of elements and innovation drivers of development in modern agricultural engineering (Fig. 3) is a prerequisite for the presence of companies in global high-tech markets, which are characterized by shifting the "center of gravity" in competition to developing high-tech products, increasing knowledge intensity, reducing time for bringing new products to the market, strict cost restrictions, high requirements for consumer characteristics.

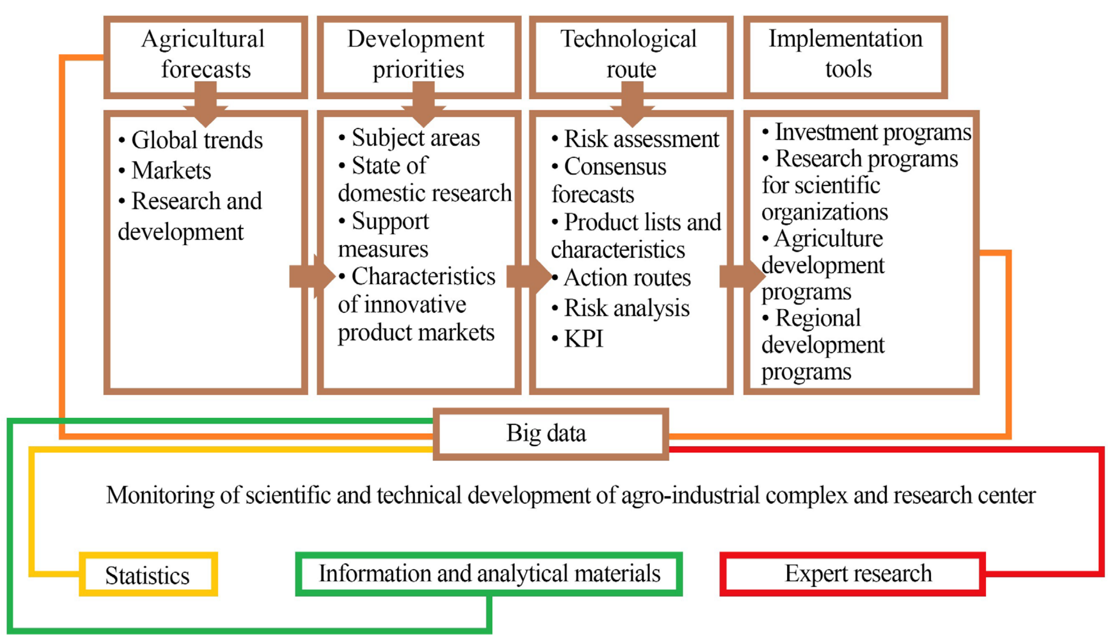

Fig. 5. Roadmap for improved development of the food industry

Criteria of innovation skills in the development of agricultural engineering provide:

– increase in production in certain industries (food) with high competition and mass production;

– public policy, which can be an incentive to modernize production using advanced automation, as well as to overcome the barrier of the "first job";

– general educational activities aimed at explaining the possibilities and benefits of using robotics in agroecosystems;

– availability of strategies, programs and national priorities for the development of robotics in agricultural engineering (Japan, South Korea, Taiwan) [34];

– cultural factor: for example, the low level of public concerns about the replacement of existing jobs by robots;

– proactive – tax policy, including benefits, as well as support for the introduction of advanced technologies (Singapore);

– China implements its own strategy for the introduction of robots: allocates large subsidies, implements the Plan for the development of the Chinese robotics industry (2016–2020).

The multilevel matrix of agricultural engineering (Table 2) is designed to "balance" a huge number of conflicting parameters and characteristics of the object as a whole, its components and parts separately. That is, it allows not only to monitor their mutual influence at different stages of the life cycle, but also in the shortest possible time to make the necessary changes and clarifications ("requirements and changes management"), for example, flexibly responding to the actions of competitors. This ensures continuous development and is a critical feature of the new digital design and modeling paradigm based on digital transformation.

The development of a matrix of food industry capacity for making management decisions to increase the stability of the technological transformation of the food industry in the formation of sustainable development of agroecosystems ensures the implementation of the following priority areas of development:

– increasing the global competitiveness of food enterprises in global high-tech markets;

– creation of a highly productive export-oriented sector developing on the basis of new production technologies;

– creation of a modern agroecosystem, where the development of a matrix of food industry capacity for making management decisions will increase the sustainability of the technological transformation of the food industry;

– training of highly qualified specialists with world-class competencies in the field of research and development, development and application of advanced technologies, usually knowledge-intensive and multidisciplinary specialists of a new type;

– transition to new business models of the food industry based on Digital Platforms/Digital twins/Enterprises of the future ("digital"/"smart"/"virtual") as the basis of the modern economy.

The development in these priority areas is most effective when implementing complex projects to create a high-tech food industry with fundamentally new consumer properties, which will provide the following effects (in order of priority):

1. Reduction of product development/production time.
2. Reduction of product development/production costs.
3. Achieving fundamentally new consumer properties.
4. Improving product quality.
5. Flexibility of production: rapid readjustment of production.
6. Implementing new business models.
7. Increasing the service life of equipment and infrastructure.
8. Increasing the service life of equipment.

In the long run, the technological transformation of the food industry will lead to the formation of sustainable development of agroecosystems and create the necessary basis for its development and improvement of living conditions. However, during the transformation period, preventive and protective measures are needed to compensate for costs that are likely to affect small businesses and other business entities. Structurally, social protection is one of the most important investments. To finance these social mechanisms, fiscal space needs to be expanded; in terms of revenue, by eliminating subsidies and raising taxes on fossil fuels, limiting and trading emission quotas and expanding capital taxation [35]. Focus on spending through state savings from administrative reforms and increasing the targeting of social protection measures for food companies undergoing technological transformation.

Negative factors and limitations affecting the technological transformation of the food industry and inhibiting the formation of sustainable development of agroecosystems are identified:

– low productivity combined with high costs: insufficient use of modern technologies, methods and crops/breeds;

– low productivity of grain production;

– relatively low cost (partly due to exchange rate and labor costs), but productivity remains low due to the lack of an urgent need to reduce costs and insufficient use of modern technologies and methods to increase productivity.

The main directions of improving the stability of the technological transformation of the food industry in the formation of sustainable development of agroecosystems are as follows:

– modernization of the technical and technological base and processes in accordance with export priorities (using incentives);

– research, training and introduction of best international practices in product processing (food industry) and operation of farms;

– creation of innovation centers for cereals and other products in order to study best practices and prepare appropriate recommendations for enterprises;

– formation of a strategy of innovative development of agricultural enterprises;

– strengthening the trend of cooperation and integration in solving problems of improving methods and mechanisms of innovative development of food enterprises at the level of local self-government;

– implementation of integration innovations at food enterprises to create conditions for the growth of innovation capacity;

– development of information, personnel, financial and legal support of the system of innovative development of the food industry for making management decisions;

– increasing the efficiency of innovative developments at food enterprises.

7. Conclusions

1. Components of the process of innovative development of modern agricultural engineering on the basis of multiple

types of agricultural products and processing products were systematized. It is proposed to take into account the significant difference in the technology of their processing and production (number of advanced technologies per 100 thousand people). The dependence of production technologies in agriculture on natural and weather conditions was revealed (share of technological innovation costs, %). The dependence in the period of production on certain types of agricultural products and processing products (number of patents, licenses, utility models per 10 thousand people) was studied. It was found that the constant presence of risk elements, instability of production processes due to local time and weather constraints require agricultural producers to have alternative management solutions for extreme conditions. And in their absence – the rapid search and application of scientific recommendations and best practices for re-equipment of production, maneuvering equipment and other resources in order to reduce or eliminate the impact of adverse environmental factors. In this process, agricultural producers should be assisted by the components of the process of innovative development of modern agricultural engineering: research, production, finance, personnel and organizations. In order to substantiate the process of innovative development of the modern agroecosystem, it is proposed to focus on the high degree of geographical separation of agricultural production and the isolation of agricultural producers from agricultural engineering.

2. Criteria of innovation skills in the development of agricultural engineering were proposed. During the study, the criteria were defined and divided into development groups: research manager; scientific strategy; persons involved in research; partnership and resources; processes, products and services; research results. The tools for constructing a matrix of food industry capacity were substantiated, where the rows contain the numbers of indicators (i=1, 2, 3, ..., n), and the columns – the names of enterprises (j=1, 2, 3, ..., m). A rational value was set for each indicator, taking into account the sensitivity factor K and the rating of enterprises, which determined their place in the matrix.

3. Components of the roadmap for improved development of the food industry: agricultural forecasts, development priorities, technological direction, implementation tools were systematized. Agricultural forecasting allows forming the image of the future agro-industrial complex on the basis of scientifically sound methods – expert surveys. Development priorities are based on scenario models. The technological direction will provide an opportunity to implement, detail the selected priorities and clearly display the routes to the goals, identify threats and risks in achieving them. The implementation tools, formed on the principle of the investment portfolio, include the task that has its own set of rational measures. It is proposed to introduce digital agriculture in order to improve the management of technological transformation of the food industry in the formation of sustainable development of agroecosystems.

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