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IMPROVING THE PRODUCTION MECHANISM OF BEEKEEPING FARMS IN THE KASHKADARYA REGION BASED ON DIGITAL TECHNOLOGIES

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Abstract: The production mechanism of beekeeping farms in the Kashkadarya region is shaped by natural and climatic conditions, biological risks, resource utilization, labor and logistics costs, and the quality of management. Traditional management methods limit the capacity for rapid monitoring and effective control of production processes amid climate change, bee diseases, pesticide exposure, and increasing market requirements. Integrating IoT sensors, Smart Beehive systems, digital monitoring, mobile applications, AI-based analytics, and digital certification into a unified production mechanism can improve resource efficiency, reduce production costs, mitigate biological risks, and enhance management effectiveness. The systematic application of these technologies provides a scientific and practical basis for improving the economic efficiency and sustainability of beekeeping farms in the Kashkadarya region.

Keywords: beekeeping, digital technologies, IoT, Smart Beehive, KPI, DAEI, production costs, biological sustainability, Kashkadarya region, digital monitoring, digital certification.

Аннотация: Производственный механизм пчеловодческих хозяйств Кашкадарьинской области формируется под воздействием природно-климатических условий, биологических рисков, эффективности использования ресурсов, затрат на труд и логистику, а также качества управления. Традиционные методы управления ограничивают возможности оперативного мониторинга и эффективного контроля производственных процессов в условиях изменения климата, распространения заболеваний пчёл, воздействия пестицидов и повышения требований рынка. Интеграция IoT-датчиков, систем Smart Beehive, цифрового мониторинга, мобильных приложений, аналитики на основе искусственного интеллекта и цифровой сертификации в единый производственный механизм способствует рациональному использованию ресурсов, снижению производственных затрат, минимизации биологических рисков и повышению эффективности управления. Системное применение данных технологий создаёт научно-практическую основу для повышения экономической эффективности и устойчивости пчеловодческих хозяйств Кашкадарьинской области.

Ключевые слова: пчеловодство, цифровые технологии, IoT, Smart Beehive, KPI, DAEI, производственные затраты, биологическая устойчивость, Кашкадарьинская область, цифровой мониторинг, цифровая сертификация.

Annotatsiya: Qashqadaryo viloyatidagi asalarichilik xo'jaliklarining ishlab chiqarish mexanizmi tabiiy-iqlim sharoitlari, biologik xavflar, resurslardan foydalanish samaradorligi, mehnat va logistika xarajatlari hamda boshqaruv sifati ta'sirida shakllanadi. An'anaviy boshqaruv usullari iqlim o'zgarishi, asalarilar kasalliklari, pestitsidlar ta'siri va bozor talablarining ortib borishi sharoitida ishlab chiqarish jarayonlarini tezkor monitoring qilish va samarali nazorat etish imkoniyatlarini cheklaydi. IoT sensorlari, Smart Beehive tizimlari, raqamli monitoring, mobil ilovalar, sun'iy intellektga asoslangan tahlil hamda raqamli sertifikatlashni yagona ishlab chiqarish mexanizmiga integratsiya qilish resurslardan oqilona foydalanish, ishlab chiqarish xarajatlarini kamaytirish, biologik xavflarni minimallashtirish va boshqaruv samaradorligini oshirish imkonini beradi. Mazkur texnologiyalarni tizimli qo'llash Qashqadaryo viloyatidagi asalarichilik xo'jaliklarining iqtisodiy samaradorligi va barqarorligini oshirish uchun ilmiy-amaliy asos yaratadi.

Kalit so'zlar: asalarichilik, raqamli texnologiyalar, IoT, Smart Beehive, KPI, DAEI, ishlab chiqarish xarajatlari, biologik barqarorlik, Qashqadaryo viloyati, raqamli monitoring, raqamli sertifikatlash.

INTRODUCTION

The application of digital technologies in agriculture is becoming a crucial factor in modernizing production processes, increasing resource efficiency, optimizing production costs, and ensuring the timeliness of management decisions. As the digital transformation process expands, opportunities for real-time monitoring

of production processes, collecting and processing large volumes of data, forecasting, and making data-driven management decisions are also expanding. This process is of particular importance for beekeeping, which is considered one of the agricultural sectors highly dependent on biological and environmental factors.

A distinctive feature of beekeeping production is that its final economic results depend not only on the level of utilization of labor, capital, and material resources but also on the biological condition of bee colonies, air temperature and humidity, food resources, flowering periods, diseases and pests, the ecological environment, and other external factors. The interaction of these factors increases the variability of production results. Therefore, in beekeeping, alongside the management of production processes based on traditional observation methods, there is a growing need to use digital monitoring and forecasting tools.

Modern digital technologies, particularly Internet of Things (IoT) sensors, Smart Beehive systems, mobile digital platforms, cloud databases, artificial intelligence, and analytical technologies, enable the continuous collection of information regarding the condition of bee colonies. Such technologies facilitate the early detection of biological risks in production and enable prompt responses by monitoring temperature, humidity, hive weight, movement activity, and other parameters. From this perspective, it is advisable to evaluate digitalization in beekeeping not only as a process of implementing technical tools but also as a factor contributing to the qualitative improvement of the production mechanism.

At the same time, an analysis of existing research indicates that, although the technical capabilities and economic significance of digital technologies in beekeeping have been studied in various areas, the evaluation of the regional production mechanism by integrating digital technologies, economic efficiency, biological sustainability, and management indicators into a unified system remains an important area for further research. Particularly in a region with unique natural and climatic conditions, such as the Kashkadarya region, the development of a digital beekeeping model requires consideration of regional, financial, institutional, and human resource factors alongside technological capabilities.

LITERATURE REVIEW

The issue of implementing digital technologies in agriculture and the beekeeping sector has been extensively studied by foreign and local researchers in recent years. An analysis of existing scientific research shows that studies in this field are primarily based on Big Data, Machine Learning, digital agriculture, Precision Beekeeping, IoT technologies, economic mechanisms, digital transformation, and regional and ecological factors.

The study conducted by Wolfert S., Ge L., Verdouw C., and Bogaardt M.-J. provides a systematic analysis of the use of Big Data technologies in agriculture. The authors emphasize that collecting, storing, processing, and transforming large volumes of data into management decisions are vital components of the Smart Farming concept [1]. This approach enables continuous monitoring of indicators in beekeeping, such as temperature, humidity, the condition of bee colonies, feeding, and productivity, as well as the making of operational decisions based on these indicators. From this perspective, this study serves as an important theoretical source for forming the information and technological foundation for the digital management of beekeeping farms.

Liakos K.G., Busato P., Moshou D., Pearson S., and Bochtis D. summarized scientific research on the use of Machine Learning technologies in agriculture [2]. The authors substantiate that Machine Learning methods enable the automation of forecasting, classification, monitoring, and decision-making processes. From the perspective of beekeeping, this approach enables the forecasting of the condition of bee colonies, the early detection of diseases, the assessment of productivity, and the early identification of production risks. Thus, this study defines the scientific and methodological foundations for the use of AI and Analytics technologies in beekeeping.

Basso B. and Antle J. investigated digital agriculture as a tool for developing sustainable agricultural systems [3]. In their approach, digitalization is linked not only to increasing economic efficiency but also to ensuring environmental and social sustainability. In beekeeping, this approach indicates the need to consider the biological condition of bees, environmental safety, the impact of pesticides, and the rational use of natural resources alongside productivity and costs. Therefore, a comprehensive assessment of economic, environmental, and social indicators is considered important when developing a digital beekeeping model.

A study conducted by Zacepins A., Brusbardis V., Meitalovs J., and Stalidzans E. within the framework of the Precision Beekeeping concept reveals the practical significance of digital monitoring technologies in beekeeping [4]. The authors analyzed the possibilities of monitoring bee colonies using sensors and remotely controlling temperature and other parameters. This approach ensures a transition from periodic observation in traditional beekeeping to real-time monitoring. This contributes to reducing the risk of bee mortality, facilitating the early detection of diseases, and optimizing the production process.

In the approaches to digital transformation developed by the European Commission, special attention

is paid to the integration of IoT, KPIs, and performance indicators in agriculture [5]. This approach indicates the need to evaluate the effectiveness of digitalization not only through the availability of technology but also through its impact on production results. The formation of key performance indicators (KPIs) in beekeeping, such as IoT coverage, cost reduction, bee mortality, productivity, the share of certified products, and digital management efficiency, is a logical continuation of this approach.

In the materials of the Food and Agriculture Organization of the United Nations (FAO), digital agriculture and Smart Farming are considered important directions for sustainable agricultural development [6]. The FAO approach emphasizes the need to consider the capabilities of small and medium-sized producers, digital infrastructure, knowledge and skills, and economic efficiency when using digital technologies. This approach requires studying the implementation of digital technologies in beekeeping not only as a technical issue but also as a comprehensive process related to financial, institutional, and human resources.

In the works of domestic researchers, considerable attention is also paid to the economic and technological development of the beekeeping industry. In particular, Farmanov J.Z. analyzed the sources and economic mechanisms for the development of beekeeping in the region in his study, "Economic Analysis of Sources and Mechanisms for the Implementation of Beekeeping Development in the Region" [7]. The significance of this work lies in its substantiation of the need to improve financial resources, economic sources, and management mechanisms for the development of beekeeping. This approach is important in terms of forming the necessary financial basis for the implementation of digital technologies.

In Farmanov J.Z.'s study titled "Analysis of Economic Sources for Financing the Transformation of Digital Technologies in Beekeeping," the financial and economic aspects of the transition to digital technologies were examined [8]. The author emphasizes the importance of funding sources and their effective use in the process of digital transformation. This approach serves as an important basis for developing mechanisms to cover investment costs when implementing IoT sensors, Smart Beehive systems, digital platforms, and other technologies in beekeeping farms.

In the study by J.Z. Farmanov dedicated to the experience of Ukraine, a foreign model for the development of the beekeeping industry was analyzed from an economic perspective [9]. The significance of this study lies in demonstrating the importance of adapting foreign experience to local conditions. The possibilities of selectively implementing foreign approaches to the development of beekeeping based on cooperation, the introduction of technological innovations, and increased production efficiency in the regions of Uzbekistan are of particular importance.

Farmanov J.Z. directly studied the role and importance of digital technologies in the beekeeping industry in his study titled "The Role and Significance of Using Digital Technologies in the Beekeeping Industry" [10]. This study aligns with the aforementioned foreign scientific works and demonstrates the economic significance of using digital monitoring, data-driven management, and modern technologies in beekeeping. Based on this approach, digitalization can be viewed as a means of increasing productivity in beekeeping farms, reducing resource consumption, and ensuring the timeliness of management decisions.

Furthermore, Farmanov J.Z.'s study, "Improving the Principles and Ecological-Geographical Features of the Beekeeping Ecosystem in the Region," examines the principles and ecological-geographical features of the beekeeping ecosystem [11]. This work demonstrates the importance of developing beekeeping based on a territorial approach. In particular, the introduction of digital technologies while taking into account natural resources, climate, vegetation base, and environmental factors contributes to achieving more effective results. Therefore, when forming a digital beekeeping model under the conditions of the Kashkadarya region, it is important to take into account the ecological and geographical characteristics of the region.

Overall, an analysis of foreign literature indicates that the concepts of Big Data, Machine Learning, IoT, and Precision Beekeeping have been identified as the primary technological foundations for the formation of digital beekeeping [1–4]. International institutional sources substantiate the need to view digitalization as a comprehensive process related to KPIs, sustainability, digital infrastructure, and human capital [5–6].

In domestic research, special attention is paid to the economic sources of beekeeping development, the financing of digital technologies, the study of foreign experience, the significance of digital technologies in the industry, and their ecological and geographical characteristics [7–11]. Thus, while foreign research primarily forms the technological and methodological foundations, domestic research reveals the economic, financial, and territorial aspects of these technologies.

RESEARCH METHODOLOGY

The research methodology is based on the study of the production mechanism through the chain "adaptation mechanisms → KPI indicators → DAEI integral assessment." This chain allows the production process in the Kashkadarya region to be interpreted as a manageable and measurable economic system.

At the first stage, adaptation mechanisms were divided into six groups: technological, regional-climatic, institutional, financial, human resource, and monitoring mechanisms. Technological adaptation covers IoT sensors, Smart Beehive systems, mobile applications, and cloud platforms. Regional-climatic adaptation involves managing biological risks under the hot and dry conditions of Kashkadarya. Institutional and financial mechanisms support the introduction of technologies through subsidies, concessional loans, public-private partnerships, and cooperation.

At the second stage, the KPI system was used to measure production results. Key indicators include IoT coverage, cost reduction, bee mortality, the share of certified honey, training coverage, productivity, and management efficiency.

At the third stage, the KPI indicators were summarized using the DAEI integral index. The index is interpreted on a scale from 0 to 1, with an increase in its value indicating an improvement in the efficiency of the digital production mechanism. The DAEI was used as a tool to identify numerical differences between regions and farms and to develop differentiated measures.

When analyzing the data, the method of comparing “pre-digitalization” and “post-digitalization” indicators was used. This approach made it possible to simultaneously assess the biological, economic, managerial, and qualitative outcomes of implementing digital technologies.

From a methodological perspective, the indicators were considered to have a practical and generalized assessment character. Therefore, the results demonstrate an empirical relationship between digitalization and efficiency. In future research, the application of regression and causal assessment models based on farm-level panel data may contribute to a more comprehensive assessment of the relationship between digitalization and production efficiency.

ANALYSIS AND RESULTS

The practical results demonstrate that the introduction of digital technologies has a positive impact on the biological stability, productivity, cost-effectiveness, and management efficiency of beekeeping farms. In particular, IoT sensors increased the accuracy of temperature and humidity control from 65–70% to 90–95%, while the Smart Beehive system reduced bee mortality from 10–12% to 6–8% (Table 1).

Table 1
Practical results of using digital technologies in honey production

No	Digital technology	Indicator	Before	After
1	IoT sensor monitoring	Temperature and humidity control accuracy, %	65–70	90–95
2	Smart Beehive	Bee mortality, %	10–12	6–8
3	Digital monitoring	Early problem detection, %	40–45	75–85
4	Data-driven management	Honey production, kg	18–20	23–26
5	AI/Analytics	Cost of honey, %	100	75–85
6	Mobile applications	Decision-making time, hours	24–48	4–8
7	Digital certification	Certified honey, %	20–25	60–80
8	Training	Technology adoption, %	15–20	50–70
9	KPI monitoring	Management efficiency, points	45–55	75–85
10	DAEI	Overall efficiency, 0–1	0.30–0.40	0.65–0.85

The table results show several important trends. First, increasing the accuracy of digital monitoring enhances the ability to manage biological risks. Second, an increase in honey production from 18–20 kg to 23–26 kg indicates an improvement in resource efficiency and productivity. Third, the use of AI/Analytics reduces costs by 15–25%. Fourth, reducing decision-making time through mobile applications from 24–48 hours to 4–8 hours increases management efficiency.

As a result of digital certification, increasing the share of certified honey from 20–25% to 60–80% enhances product traceability and market confidence. The increase in training and digital literacy coverage from 15–20% to 50–70% indicates that human capital is an integral part of digital transformation.

The increase in the overall DAEI efficiency indicator from 0.30–0.40 to 0.65–0.85 indicates that the integrated application of digital technologies, rather than their individual use, yields more effective results. Thus, the main effect of digital transformation stems from the integration of IoT, monitoring, management, certification, and personnel training within a unified system.

The proposed model for assessing the production mechanism in the Kashkadarya region consists of three main links. The first link comprises adaptation mechanisms, which involve the selection of digital tools that correspond to the natural, climatic, technological, and institutional characteristics of the region. The second link consists of measuring practical results through KPIs. The third link provides a strategic assessment by summarizing KPIs within the DAEI integral index.

The scope of IoT coverage reflects the level of development of digital infrastructure. On farms with high IoT coverage, temperature, humidity, and the condition of bee colonies are monitored in real time. This facilitates the early identification of diseases, climatic risks, and other biological challenges.

Cost reduction is considered a primary indicator of economic efficiency. Digital management enables accurate planning of feed, labor, and logistics costs, facilitates the identification of excessive expenditures, and optimizes resource utilization standards.

The decrease in bee mortality reflects biological stability, while the increase in the share of certified honey reflects product quality and compliance with market requirements. Training coverage demonstrates the capacity to adopt digital technologies. By summarizing all these indicators using the DAEI, the comprehensive efficiency of the production mechanism is determined. This approach facilitates the transition of production from traditional experience-based management to data-driven management.

Foreign experience can be selectively integrated into three main areas. The European model emphasizes environmental monitoring, product quality control, and digital certification. The U.S. model enhances the use of AI, Big Data, and forecasting capabilities. The Asian model focuses on the widespread implementation of affordable and flexible IoT solutions for small and medium-sized enterprises. The combination of these three approaches contributes to the formation of an optimal digital production mechanism under the conditions of Kashkadarya.

For Kashkadarya, it is advisable to adopt environmental monitoring and traceability practices from European experience, AI-based forecasting from U.S. experience, and affordable sensors and modular technological solutions from Asian experience. Such a selective approach involves adapting foreign models to local infrastructure, financial capabilities, and climatic conditions rather than applying them uniformly.

CONCLUSIONS AND SUGGESTIONS

Improving the production mechanism of beekeeping farms in the Kashkadarya region based on digital technologies requires the integration of technological, territorial-climatic, institutional, financial, human resource, and monitoring mechanisms into a unified system.

IoT sensors, Smart Beehive systems, digital monitoring, mobile applications, and AI/Analytics enable real-time monitoring of the biological and economic parameters of the production process.

As a result of digitalization, the accuracy of temperature and humidity monitoring can be increased to 90–95%, honey production can be increased to 23–26 kg, bee mortality can be reduced to 6–8%, and production costs can be reduced by 15–25%.

The DAEI integral index is proposed as a practical indicator for comprehensively assessing the efficiency of digital beekeeping, identifying numerical differences between regions, and developing differentiated management measures.

In the context of Kashkadarya, it is advisable to selectively integrate and regionally adapt European practices in environmental monitoring and certification, U.S. practices in AI and Big Data, and Asian approaches to affordable IoT solutions.

To accelerate digital transformation, it is necessary to jointly implement state subsidies, preferential loans, public-private partnerships, cooperation mechanisms, training programs, and pilot projects such as Smart Apiary.

In future studies, it is recommended to determine the causal effects of DAEI components on production costs, yields, income, and profits using econometric models based on farm-level panel data.

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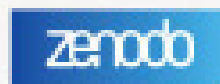
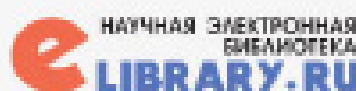
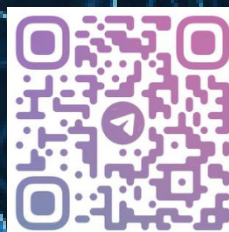
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