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ECONOMIC EFFICIENCY OF AUTOMATED QUALITY CONTROL SYSTEMS IN THE FOOD INDUSTRY

S u m m a r y

Background. This study aims to analyze the impact of implementing automated quality control systems on the economic efficiency of companies in the food sector. The methodological framework combines a comprehensive analysis of production, technological and economic aspects of adopting automated solutions, including the elements of artificial intelligence, machine vision, sensor systems and integration with digital platforms. Special attention is given to the experience of Azersun Holding (Azerbaijan) and Myronivsky Hliboproduct (Ukraine).

Results and Conclusions. At Azersun, the implementation of a corporate digital platform covered over 30 enterprises, including two food plants and retail chains, enabling centralized management and improved planning accuracy. The company's revenue grew from 1,003 million to 1,810 million manats between 2019 and 2023. Myronivsky Hliboproduct implemented an AI-powered virtual technologist and an automated cold storage facility for 20,300 pallets with digital management, reducing energy costs by 30 % and improving temperature control accuracy. The company's revenue increased from 2,056 million to 3,046 million dollars between 2019 and 2024, despite crises such as the pandemic and military conflict. The findings confirm that the implementation of automated quality control systems transforms the quality assurance system from a selective and retrospective to a continuous and preventive one, enhancing management efficiency, reducing defect rates and strengthening trust from international partners. The practical significance of this research lies in its applicability for food producers, process engineers and managers in selecting and deploying effective automated quality control solutions to enhance competitiveness and comply with international standards.

Keywords: digital technologies, industrial production, sustainable development, technological integration, financial performance

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Introduction

The food industry operates under intense competition, increasingly stringent regulatory requirements and growing consumer expectations regarding product quality and safety. In this context, the adoption of innovative solutions that improve the efficiency of production processes becomes particularly relevant. One such solution is the implementation of automated quality control systems, which ensure continuous monitoring of technological parameters, precise defect detection and minimization of the human factor.

Despite the broad technical capabilities of such systems, their adoption can pose economic challenges due to substantial initial investments. The lack of an objective assessment of the economic efficiency of these technologies hinders management decision-making and slows industry modernization. This results in the limited dissemination of automated control systems, especially among small and medium-sized producers.

Research by various scholars has revealed the multifaceted impact of automated quality control systems on food industry production processes. Wang and Li [68] conducted a study in meat processing enterprises where the introduction of automated systems reduced technological losses. This not only decreased the volume of non-marketable products, but also increased the output of acceptable products, significantly improving the companies' economic performance. Matvieiev et al. [42] focused on the dairy industry, where automation halved the duration of control operations while increasing the accuracy of detecting microbiological and physical deviations. The acceleration of control processes enhanced production throughput and reduced the workload on laboratory staff, positively affecting overall production efficiency.

Wu and Liu [69] assessed the economic efficiency of automated systems compared to traditional control methods. He noted that automation reduced labor costs for quality inspectors and expenses associated with reprocessing defective batches. Idrisli and Orujov [31], exploring the impact of automation on food safety, concluded that automated systems detect potentially hazardous deviations – especially in temperature and microbiological monitoring – more quickly and accurately. This led to fewer violations identified during inspections, reducing the risk of fines and reputational damage.

Mešić et al. [43] highlighted the flexibility and adaptability of modern systems to various food production types – from confectionery to canning. He emphasized that the universality of automated platforms makes them feasible even in enterprises with complex technological structures, expanding opportunities for automation at scale. Chhetri [18] developed a model for assessing automation efficiency, accounting not only for direct economic effects such as cost reduction but also indirect benefits such as increased partner trust and customer loyalty driven by consistent product quality, ultimately contributing to business growth.

Dutta et al. [20] drew attention to the marketing benefits of automation, noting that it enables enterprises to obtain international quality certifications such as ISO 22000:2018 [33] and Food safety system certification 22000 [34]. These certifications facilitated entry into export markets and enhanced brand image, opening new commercial opportunities. In this context, Huseynov and Orujzada [30] pointed out a significant increase in labor productivity following automation: personnel were reassigned to higher-skilled tasks, and total output increased due to reduced downtime and fewer production errors.

Khorolskyi et al. [36] demonstrated that product return rates from distributors and retailers decreased after the implementation of automated control, strengthening business relationships and saving significant amounts on logistics and complaints. Bhanushali [14] conducted a comparative analysis of companies using manual versus automated quality control. His findings showed that automation improved the objectivity and precision of product assessments, reduced conflicts with consumers and regulators and facilitated certification and inspections.

The reviewed literature confirms that automated quality control systems generally contribute to reduced defect rates, higher productivity, improved food safety and lower economic losses. The authors examined various aspects of implementation – from technical efficiency to return on investment and impact on corporate reputation. However, there remains a need for a targeted analysis of the economic efficiency of such systems, considering factors such as enterprise size, product type, automation level and the current state of quality control. Moreover, integration barriers in transitioning from traditional to automated systems, as well as differences in effectiveness depending on the level of digital maturity, are still insufficiently explored.

The aim of this study is to assess the economic efficiency of implementing automated quality control systems in the food industries of Azerbaijan and Ukraine. The research objectives include evaluating the economic effects of these systems, analyzing the factors influencing their efficiency depending on enterprise and product type and identifying barriers and conditions for the successful integration of automation into existing production processes.

Materials and methods

This study employed a comprehensive approach combining qualitative and structural-analytical methods to investigate the impact of automated quality control systems on the economic performance of food industry enterprises. Key research objects included leading food companies from countries with varying levels of economic development and digital maturity, such as Deutsches Milchkontor GmbH (DMK) [61] (Germany), FrieslandCampina [22] (Netherlands), Tyson Foods [50] and Nestlé USA [62], and Ajinomoto [63] (Japan). The objective of this selection was to explore international best practices in implementing automated quality control systems in technologically advanced environments, thereby establishing benchmarks for efficiency and identifying common approaches to digital transformation in the food sector. The selection of the five international companies was purposive rather than random or convenience-based. Beyond technological advancement, the sampling was guided by comparative analytical logic: each company represents a distinct regional and industrial model of digital transformation (European cooperative, multinational conglomerate, vertically integrated producer and innovation-oriented Asian corporation). This allowed the study to compare implementation strategies, investment efficiency and organizational practices across varied economic, cultural and regulatory contexts.

A structured analysis was conducted to cover projects implemented at these companies, focusing on automated laboratories, packaging lines with integrated quality control, digital management platforms and solutions based on artificial intelligence and sensor technologies. The analysis evaluated the integration of AI, machine vision, sensor and predictive systems into production cycles, based on criteria such as the degree of integration with digital platforms, automation levels, scalability and interaction with the industrial Internet of Things.

Particular focus was placed on comparing national automation contexts. For this, data from the State Statistical Committee of the Republic of Azerbaijan [32] was used to analyze food industry indicators from 2015 to 2023. As of the time of the study, 2024 data was not been published yet. Indicators included a number of operating food enterprises, registered individual entrepreneurs, the value of industrial output, the industrial production index and the share of the food industry in the total volume of industrial production. A content analysis of regulatory and strategic documents was also carried out, with special emphasis on the “Azerbaijan 2030: National Priorities for Socio-Economic Development” strategy, which outlines industrial modernization and digitalization goals [46]. This analysis helped establish the macroeconomic context and development potential of the national food industry.

In parallel, to identify both common and country-specific factors of digital transformation, the Ukrainian context was explored using data from the State Statistics Service of Ukraine [59] for 2019 ÷ 2023. Similar statistical indicators were analyzed. The sustainable development strategy “Ukraine 2030” was also reviewed, which outlines key priorities in digitalization, energy efficiency, agri-industrial development and transition to sustainable production models [65].

To assess the impact of automated quality control systems on the economic performance of food industry enterprises in Ukraine and Azerbaijan, structural-analytical and comparative-statistical methods were applied. Data on public procurement from the Prozorro [6] system for 2023-2024 (under Common Procurement Vocabulary (CPV) codes 71731000-1 and 38900000-4) were used to reflect investment activity in laboratory and control equipment. Additionally, information on digitalization programs in Azerbaijan’s food industry, published on the KOBIA platform, was analyzed [12]. MIGA's Smart Farm Guarantee Project in the Kyrgyz Republic supports the construction and operation of a 10-hectare smart farm located near Bishkek was also reviewed [19].

Two leading agro-industrial holdings were selected for in-depth analysis: Azersun Holding [23] (Azerbaijan) and Myronivsky Hliboproduct (MHP) (2025) [24]. These companies were chosen due to their scale, active digital transformation and the availability of structured financial reports over multiple years. To assess changes in the financial and economic performance resulting from the implementation of automated quality control systems, key indicators such as total revenue, net profit, asset value and equity capital were examined. The analysis covered the period from 2019 to 2023, allowing for the inclusion of both pre-crisis and post-pandemic phases. As of the study date, full 2024 financial reports were not publicly available. At Azersun Holding, particular attention was given to projects involving the creation of automated laboratories, the modernization of packaging lines with integrated quality control and the integration of production facilities with a corporate digital platform. In the case of Myronivsky Hliboproduct, initiatives in logistics digitalization (including an automated cold storage facility), the introduction of an AI-powered “virtual technologist” system and investments in sustainable energy and digital quality control platforms were examined.

Results

In the context of rapid industrial digitalization – especially in the food sector, where quality and safety requirements are of critical importance – automated quality control systems (AQCS) have become an essential element of sustainable and efficient production. These systems comprise a set of technical and software tools designed for real-time monitoring, evaluation and management of product quality parameters [55]. The AQCS implementations have led to outcomes: some workforce reductions (particularly for routine inspection tasks), significant requalification needs and the creation of higher-skilled technical positions for those who can work alongside automated systems. Human expertise remains valuable, particularly in the areas requiring intuition, creativity and complex problem-solving, with quality control and final inspection still performed by skilled human workers who can identify subtle defects. The concept of an automated quality control system goes far beyond the simple replacement of human labor with machines. These are intelligent solutions that integrate into production lines, collect data from sensors, cameras and other devices, analyze information using algorithms – including artificial intelligence (AI) – and respond promptly to deviations from predefined standards. Such systems do not merely register defects; they prevent them by intervening in the process before a fault occurs [5].

The core functions of AQCS include measurement, comparison and logging of indicators, as well as automatic decision-making in response to deviations from set quality standards. For example, in dairy bottling lines, the system may monitor packaging integrity, product temperature and volume conformity. In case of discrepancies, it either automatically adjusts equipment settings or removes the defective unit. In this way, quality control evolves from being selective and retrospective to continuous and preventive [60]. Beyond their primary function – ensuring compliance with quality standards – AQCS also perform a range of auxiliary tasks. These include statistical recording, report generation, monitoring quality trends over time and across production batches, enabling the detection of hidden issues and proactive responses to potential risks [4]. Looking ahead, integration with other digital platforms such as enterprise resource planning (ERP) or manufacturing execution system (MES) allows for the creation of a fully digitally managed production environment.

One of the most widely used technologies in the food industry is machine vision – the use of high-resolution cameras combined with image processing algorithms to assess the visual appearance of products [47]. Such systems can detect packaging defects, structural damage, contamination, incorrect labelling or deviations in the geometric parameters of a product. Machine vision is particularly effective on high-speed production lines, where manual inspection becomes inefficient [15]. Sensor technology also plays a crucial role in automation. Sensors measuring temperature, humidity, pressure, density and other physical parameters allow continuous monitoring of both a product condition and a technological environment. Modern sensors operate reliably in aggressive environments and can be integrated with industrial controllers, forming a unified, responsive network for detecting any deviation from technological norms [57].

Robotic systems incorporating AI are increasingly being used – not only to detect issues, but also to decide on corrective actions [17; 37]. For example, in packaging lines, AI can predict the likelihood of deviations and automatically recalibrate equipment, thereby reducing the risk of defects. Another key trend is the integration of AQCS into enterprise-wide digital ecosystems, including ERP, MES and supervisory control and data acquisition (SCADA) systems. This provides a holistic view of production, linking quality control with logistics, procurement and financial processes [45]. Such an approach enables full oversight – from raw material supply to finished product shipment – ensuring that each control stage is accounted for.

Modern AQCS are increasingly cloud-based, using Internet of Things (IoT) technologies [10; 49]. This enables the collection and analysis of large volumes of data, the optimization of processes based on historical statistics, predictive maintenance scheduling and even automatic generation of service protocols. Moreover, in specific segments, laser, ultrasonic and spectral analysis methods are being actively adopted. These allow for the determination of a product's chemical composition without compromising its integrity – particularly relevant in the production of juice, oil, meat, and dairy produce, where composition and homogeneity are critical [26]. The adoption of such technologies not only enhances accuracy and reliability in quality control, but also paves the way for a smart manufacturing model, where data-driven management governs all stages – from raw materials to packaging [48]. As a result, businesses benefit not only from guaranteed quality, but also from measurable economic advantages: reduced waste, fewer product complaints, increased productivity and stronger consumer and partner trust.

These advanced control technologies are being adopted in countries with varying levels of economic development, and their economic impact is both concrete and quantifiable. In Germany, one of Europe’s most technologically advanced economies, the implementation of AQCS is a component of the national “Industry 4.0” strategy [66]. For example, at the DMK Group’s dairy plants, systems monitor fat content, temperature and microbiological parameters of milk in real time [61]. The DMK Group is Germany's largest dairy cooperative, processing around 5.1 to 6.5 billion kilograms of milk annually. It is a key supplier to German food retail, producing a wide range of dairy products including cheese, quark, ice cream, baby food, vegan products, fresh dairy products and ingredients for industrial use. The company is known for brands such as MILRAM, Oldenburger, Humana and Alete, which are trusted both in Germany and internationally. This has reduced the defect rate to under 0.3 % of total output and ensured compliance with IFS Food and BRC standards. According to internal reports, the average return on investment (ROI) for AQCS implementation is approximately 18 months, with operational cost reductions of 10 ÷ 15 %.

In the Netherlands, a leading agri-food exporter, the automation of quality control is a key factor for accessing markets in Asia and North America [67]. Companies such as FrieslandCampina [22] operate fully integrated digital platforms that consolidate quality control, logistics and certification. FrieslandCampina is a Dutch multinational dairy cooperative headquartered in Amersfoort, the Netherlands. It is one of the world's largest dairy cooperatives and among the top five dairy companies globally, with annual revenues nearing 13 billion euros as of 2024. Automated systems detect even minor packaging faults, storage temperature deviations and expiry date issues. This has enabled enterprises to increase exports by 20 % and reduce international complaints to nearly zero.

In the USA, quality control automation forms part of a broader digital transformation strategy. Tyson Foods, Inc. is one of the world's largest food companies and a recognized leader in protein, headquartered in Springdale, Arkansas. At Tyson Foods [50], neural network-based image analysis algorithms are used to detect not only defects, but also their root causes. In the meat processing segment, machine vision systems have reduced product returns by 37 % within the first year of use. Nestlé USA is part of Nestlé S.A., the world's largest food and beverage company, which focuses heavily on innovation, scale and digital transformation to drive growth and operational efficiency. At Nestlé USA [62], automated quality control platforms are integrated with SAP (Systems, Applications and Products) ERP systems, enabling full traceability and minimizing manual intervention. The company's internal evaluation estimates the economic benefit of automation at one production site to be around USD 1.8 million per year.

In Japan, where microbiological safety and precision are paramount, automation has taken the form of "smart laboratories". Ajinomoto Co., Inc. is a diversified global food and biotechnology company headquartered in Tokyo, Japan, with a foundational history dating back to 1909. It is renowned for its seasoning products, especially monosodium glutamate (MSG), and has expanded its portfolio to include processed food, frozen food, amino acids and health-related products. Companies such as Ajinomoto [63] have implemented robotic sampling and analysis stations connected to centralized information systems. Using AI, these systems analyze and forecast the quality of upcoming production batches, enabling pre-emptive adjustments before mass production begins. As a result, critical incidents have decreased by 40 %, and quality control costs have fallen by 22 %.

In the Kyrgyz Republic, automation and digital technologies in the food sector primarily focus on smart agricultural platforms and optimization of agri-food chains to enhance productivity and market access. For instance, digital agriculture platforms incorporating IoT, AI and blockchain are used to improve logistics, yield forecasting and supply chain efficiency, boosting exports notably to China from USD 50 million in 2001 to USD 900 million in 2023. Moreover, initiatives like MIGA's Smart Farm Guarantee Project introduce automated hydroponic greenhouses with controlled growing systems, indicating a shift towards precision farming in Kyrgyzstan [24]. MIGA's Smart Farm Guarantee Project is an initiative supported by the Multilateral Investment Guarantee Agency (MIGA), part of the World Bank Group, aimed at fostering advanced agricultural development in the Kyrgyz Republic. The project involves a 10-hectare smart farm located near Bishkek, which features hydroponic greenhouses with automated systems that comprehensively control the growing environment for vegetables and flowers. Despite progress, challenges such as limited digital infrastructure and financial constraints remain, and smallholder farmers predominantly operate with traditional methods, although there is openness to adopting value-added processing lines supported by targeted capacity-building programs [2].

The levels of automation and intelligent integration demonstrated by the above companies clearly show a significant impact on productivity and cost reduction. This is particularly important for countries with developing food industries, where such technologies can improve product quality and business sustainability, thereby creating favorable conditions for economic growth and enhanced export potential. The food industry of Azerbaijan plays a vital role in the structure of the national economy. This is due to the country's agrarian foundations, its strategic focus on developing the non-oil sector and ensuring food security. Table 1 presents key indicators of Azerbaijan's food industry.

Table 1. Key indicators of the food industry in Azerbaijan, 2015 ÷ 2023.
Tabela 1. Kluczowe wskaźniki przemysłu spożywczego w Azerbejdżanie w latach 2015 ÷ 2023.

Indicators	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of operating enterprises	382	391	361	393	449	487	540	587	641
– of which government-owned	18	16	7	7	9	9	9	7	8
– non-government	364	375	354	386	440	478	531	580	633
Number of individual entrepreneurs	4,079	4,290	4,508	4,754	5,252	6,042	6,623	6,924	7,456
Industrial output (goods/services), mln AZN/bln USD	2,307.6 / 1.358	2,964.7 /1.744	2,999.8 /1.765	3,050.8 /1.795	3,584.8 /2.109	3,884.3 /2.285	4,495.6 /2.644	4,890.9 /2.876	4,547.6 /2.675
Industrial production index [%]	102.9	104.8	101.0	101.3	110.8	97.3	112.6	108.2	109.2
Share of food industry in total output [%]	8.8	9.1	7.4	6.4	7.6	10.4	8.1	5.7	6.8

Explanatory notes / Objaśnienia: compiled by the authors based on State Statistical Committee of the Republic of Azerbaijan [32] / zebrane przez autorów na podstawie Państwowego Komitetu Statystycznego Republiki Azerbejdżanu [32]

The number of active enterprises has nearly doubled – from 382 to 641 – reflecting increased investment activity and interest in food processing. Growth has been especially noticeable among non-governmental organizations, whose share has steadily increased, while the number of state-owned enterprises has remained minimal. This confirms a shift toward private initiative in the sector. There has also been consistent growth in the number of individual entrepreneurs – from 4,079 to 7,456 – indicating the development of small businesses within the industry. The value of output increased until 2022, peaking at nearly AZN 4.9 billion ($2.882 billion), but declined in 2023, possibly due to external economic factors or changes in market conditions. The industrial production index fluctuated year-on-year, but remained above 100 %, indicating positive production dynamics. However, the share of the food industry in total industrial output showed a downward trend – from 8.8 % in 2015 to 6.8 % in 2023 – possibly indicating faster growth in other sectors or a relative slowdown in the food industry's development pace.

The sector demonstrates positive dynamics due to increasing investment, equipment modernization, the expansion of export deliveries and the adoption of modern quality standards. More than 600 food industry enterprises operate in the country, covering milk and meat processing, the production of bakery and confectionery products, the preservation of fruit and vegetables, as well as the manufacture of soft drinks, wine and tea products. The leading regions for food industry specialization include Baku, Ganja, Lankaran, Sheki and Nakhchivan. Major companies such as Azersun Holding, Milk-Pro, Bal Milk, Gilan Holding and Atena are actively expanding production capacities and exporting products to the Commonwealth of Independent States (CIS) countries, the Middle East and the European Union (EU) [32].

The state places great importance on the development of the food industry, identifying it as one of the priority areas within the framework of the "Azerbaijan 2030: National Priorities for Socio-Economic Development" strategy [46]. Government support programs are being implemented to subsidize agricultural production, finance processing enterprises, establish logistics centers and stimulate exports. Additionally, tax incentives and grants are provided to support production modernization and attract investment. As a result, the sector has attracted significant domestic and foreign investment, modern processing plants have been established, new packaging and filling lines introduced and the digitalization of certain processes initiated.

In 2024, measures of state support for digitalization in the Azerbaijani food industry were significantly expanded. In particular, within the frameworks of the "digiMATE" and "CTO-as-a-Service" programs, support was provided to 62 enterprises, 26 of which were directly involved in the implementation of automated quality control systems. The total amount of funding amounted to 11.8 million manats ($6,941,176.47), which is 23 % more than in 2023 [12]. The main investment areas included the purchase of robotic laboratory stations, sensor platforms for monitoring microbiological indicators and hardware-software solutions for predictive analysis based on AI.

Nonetheless, the sector faces a number of challenges. Most small and medium-sized enterprises (SMEs) continue to suffer from insufficient technical equipment, a low degree of quality control automation, limited access to international markets due to non-compliance with global standards, dependence on imported packaging materials, equipment and components, as well as a shortage of qualified personnel – especially in food technology and quality management.

Despite these constraints, Azerbaijan’s food industry possesses significant potential. Prospects for development are linked to the deeper processing of agricultural raw materials domestically, the introduction of automated quality control systems, the digitalization of logistics and production processes and the expansion of exports within international initiatives such as “One Belt – One Road” and strengthened cooperation with Turkic-speaking countries [58]. Thus, the food industry could become not only a key component of the national economy, but also a driver of sustainable economic growth, job creation and enhanced food security.

Ukraine’s food industry is one of the most dynamically developing sectors of the national economy and traditionally ranks high in both production volume and export potential. The country has a strong agricultural base, which provides raw materials for deep processing, as well as a widespread network of food enterprises targeting both domestic and foreign markets. Table 2 presents the key indicators of the food industry in Ukraine.

The number of active business entities fluctuated between 13,000 and 15,000, with a decline in 2022 due to the war. The number of sole proprietors gradually declined until 2022, but rose again in 2023, indicating a revival of small business activity. Sales volume showed considerable volatility: after steady growth until 2018, there was a sharp drop in 2019 and 2020, followed by a rise in 2021 and a renewed decline in 2022 and 2023, reflecting the impact of economic hardship and armed conflict. The industrial production index also showed instability, dropping to 79 % in 2022, but recovering to 115.6 % in 2023, indicating a production rebound. The food industry’s share in total industrial production remained around 20 %, underscoring its importance to the national economy, despite the challenges posed by the war since 2022.

The key areas include the production of meat and dairy products, bakery and confectionery items, oils and fats, alcoholic and non-alcoholic beverages, and the processing of vegetables, fruit and grains. Major food industry hubs include Kyiv, Vinnytsia, Poltava, Kharkiv, Lviv, Dnipro, Odesa and Ternopil. Leading companies such as MHP, Roshen, Obolon, AVK, Kernel and Galychyna possess advanced production capacities and active export strategies. Due to high quality standards and competitive pricing, Ukraine exports food products to more than 100 countries, including the EU, China, the Middle East and Africa [59]. Special attention is paid to compliance with international standards such as ISO 22000:2018 [33], Food safety system certification 22000 [25], British Retail Consortium (BRC) and International Featured Standards (IFS), which has become a crucial requirement for entering foreign markets and attracting international investment.

Table 2. Key indicators of Ukraine's food industry, 2015 ÷ 2023.
Tabela 2. Kluczowe wskaźniki przemysłu spożywczego Ukrainy w latach 2015 ÷ 2023.

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of active business entities	15,264	14,447	14,270	14,681	15,309	15,190	15,109	13,023	15,374
incl. sole proprietors	10,355	9,866	9,314	9,533	9,960	9,857	9,521	8,818	10,534
Number of active enterprises	4,909	4,581	4,956	5,148	5,349	5,333	5,588	4,205	4,840
Sales of goods and services (UAH billion) / (USD billion)	60.0/ 1.432	69.9/ 1.669	103.2/ 2.463	117.3/ 2.8	85.4/ 2.039	70.9/ 1.693	121.3/2 .896	58.2/ 1.389	41.0/ 0.979
Industrial production index [%]	88.6	108.9	107.1	98.5	103.9	99.5	94.1	79.0	115.6
Share of industry in total industrial output [%]	22.4	21.4	20.9	19.4	20.4	21.0	18.0	18.7	20.3

Explanatory notes / Objaśnienia: compiled by the authors based on State Statistics Service of Ukraine [59] / opracowanie własne autorów na podstawie State Statistics Service of Ukraine [59].

State policy towards the food industry focuses on promoting exports, digital transformation and enhancing product safety. Within the framework of various programs, including the Ukraine 2030 Sustainable Development Strategy, support is provided to agri-food clusters, the deregulation of production controls is underway and international certification standards are being introduced [65]. International donors and investment funds play a significant role by financing production modernization, the development of logistics chains and the implementation of smart technologies in manufacturing processes.

In 2024, as part of an analysis of investment activity in the field of AQCS, data from the Prozorro [6] public procurement system was processed using CPV codes 71731000-1 (quality control services) and 38900000-4 (laboratory, optical and precision equipment). A total of 312 tenders were registered during the reporting period – 17.2 % more than in 2023 (266 tenders). The total value of concluded contracts in these categories reached UAH 487 million, exceeding the previous year's figure by 19.6 %. The significant increase in procurement volumes is attributed to the growing demand for automated laboratory systems, multisensor quality analysis technologies and the integration of equipment with enterprise ERP and MES systems.

However, the industry faces a number of systemic problems, particularly in the context of war and damaged logistics infrastructure. The key challenges include the destruction of production facilities in frontline and occupied areas, rising production costs due to the energy crisis and difficulties in exporting products due to port blockades and transport restrictions. Furthermore, the sector continues to suffer from low levels of quality control automation, especially among SMEs, which reduces efficiency and undermines competitiveness in the global market. Many manufacturers continue to struggle with the modernization of equipment, transitioning to zero-waste technologies, implementing advanced information systems and complying with environmental, social and governance (ESG) standards [28, 53].

Despite these difficulties, Ukraine's food industry shows resilience and an ability to adapt to new challenges. Many enterprises have quickly restructured logistics, shifted exports to land corridors and actively invested in digital quality management platforms and automated monitoring systems. Thus, the introduction of AQCS is becoming an increasingly popular solution for enhancing efficiency, reducing losses and strengthening trust from international partners. The export-oriented segment – such as grain processors, oil manufacturers and confectionery producers – is especially active in this area, focusing on consistent quality and rapid adaptation to foreign customer requirements. In the case of Ukraine, contextual factors such as the ongoing war, high energy dependence and fluctuating market openness significantly moderate the relationship between automation and performance outcomes. The war disrupts logistics and infrastructure, which limits the short-term benefits of automation, yet simultaneously accelerates its adoption as a resilience strategy to compensate for labor shortages and production risks [64, 70]. Moreover, energy instability and constrained export routes reduce cost-efficiency gains, making automation most effective in enterprises capable of integrating energy-saving technologies and diversifying supply chains to maintain competitiveness in volatile markets.

The implementation of automated quality control systems in the food industry in Azerbaijan and Ukraine demonstrates significant economic and operational advantages. Two leading enterprises were analyzed: Azersun Holding [23] in Azerbaijan and Myronivsky Hliboproduct [24] in Ukraine. Founded in 1991, Azersun Holding is one of the largest agro-industrial conglomerates in Azerbaijan, comprising over 30 enterprises that cover the full production cycle – from agriculture and processing to packaging, logistics and retail. Since 2022, the company has been actively implementing a digital transformation strategy aimed at improving management efficiency and product quality through the deployment of automated quality control systems and advanced digital solutions. A key stage in this process was the implementation of the SAP corporate platform, covering ERP, Human Capital Management (HCM), Business Planning and Consolidation (BPC) and Ariba modules. By the end of 2023, both production facilities (including Baki Qida Yağ Fabriki and Sun Tea Çay Fabriki) and retail chains (Bazarstore and Al Market) had been transferred to SAP ERP [13]. As a result, Azersun was able to centralize planning, ensure process transparency, enhance managerial decision-making accuracy and reduce costs.

In parallel with management digitalization, the company is actively automating its production processes. For instance, the cannery in Biləsuvar uses modern packaging lines for glass, tin and aseptic containers, equipped with integrated quality control modules capable of real-time detection of product parameter deviations. Monitoring is conducted according to various criteria, including hermeticity, the mass share of the main component, thermal treatment levels and packaging appearance [21]. Furthermore, Azersun employs automated laboratory complexes for analyzing raw materials and finished products, minimizing human error and ensuring consistent quality across all stages.

The economic effect of these implementations is reflected in increased productivity, reduced returns and complaints, lower quality control costs and higher export volumes. In particular, through automation and certification in line with international standards such as the International Organization for Standardization (ISO) and Hazard Analysis and Critical Control Points (HACCP), Azersun has significantly strengthened its presence in the CIS, Middle Eastern and Central Asian markets. The company is also actively engaged in environmental initiatives. For example, a waste paper recycling line was launched at the paper mill in Sumgait, reducing air pollution by 73 % compared to virgin fiber production [41]. Additionally, Azersun collaborates with the airline AZAL under the program "Cleaner World – Brighter Sky!", aimed at reducing paper waste and promoting sustainable resource consumption [11]. In 2024, Azersun Holding [23] increased its export of processed food products by 17 %, while the number of customer complaints dropped by 42 %, due to the integration of a digital quality control platform with production lines. Table 3 presents the company's key financial indicators.

Table 3. Key financial indicators of Azersun Holding, 2019 ÷ 2023 (million manats) / (USD).
Tabela 3. Kluczowe wskaźniki finansowe Azersun Holding, 2019 ÷ 2023 (mln manatów) / (USD).

Indicator	2019	2020	2021	2022	2023
Revenue	1,003.9 / 590,500,000	1,212.2 / 713,000,000	1,522.4 / 895,700,000	1,825.4 / 1,074,000,000	1,810.9 / 1,065,000,000
Profit	10.1 / 5.94 million	24.1 / 14.17 million	28.9 / 17 million	16.1 / 9.47 million	60.7 / 35.70 million
Assets	810.3 / 476.6 million	950.0 / 558.8 million	1,028.5 / 605 million	1,163.4 / 684.5 million	1,071.6 / 629.5 million
Capital	350.1 / 205.9 million	382.4 / 224.9 million	395.9 / 232.9 million	416.8 / 245.2 million	637.8 / 375.1 million

Explanatory notes / Objaśnienia: compiled by the authors based on Azersun Holding [23] / zebrane przez autorów na podstawie Azersun Holding [23]

The company has demonstrated steady growth in key financial indicators despite global economic challenges, including the COVID-19 pandemic. Revenue increased from approximately 1,003.9 million manats ($590.5 million) in 2019 to 1,810.9 million manats ($1.065 billion) in 2023, indicating expansion in production capacity and a successful diversification strategy. Although profit showed some fluctuation, it reached 60.7 million manats ($35.7 million) in 2023. The growth of assets and capital reflects effective resource management and investment in development, including the deployment of automated quality control systems and digital solutions, which contributed to improved operational efficiency and stronger market positions domestically and internationally.

Myronivsky Hliboproduct (MHP) is the largest agricultural and food company in Ukraine, specializing primarily in the production and export of chicken meat. MHP is a poultry producer in Ukraine and one of the industry leaders in Europe. The company actively adopts digital technologies and automation to optimize production processes. One of its key projects is an automated cold storage warehouse in the Vinnytsia region. Measuring 68×55 meters with a height of 20 meters, it accommodates 20,300 pallets and is equipped with three automated pallet storage and retrieval machines. The viadat warehouse management system oversees the entire process, including temperature control and product shelf life, ensuring a continuous cold chain and reducing energy consumption by 30 % compared to conventional warehouses [9].

MHP has also implemented the "Smart Technologist Assistant", a virtual livestock technician based on artificial intelligence, which analyses data from poultry farms to detect production process deviations [44]. This solution helps improve flock uniformity, enhances weight prediction accuracy and lowers poultry mortality rates. Within its vertically integrated model, MHP controls the entire production cycle – from grain cultivation to meat processing and packaging. The company also invests in sustainable energy projects, including biogas plants, which allow for the efficient use of production waste and a reduction in greenhouse gas emissions. Due to these efforts, MHP [24] ensures high product quality compliant with international standards such as ISO 22000:2018 [33] and HACCP, and continues to expand its exports to over 70 countries worldwide. Table 4 presents the company's key financial indicators.

However, since comprehensive data for Azerbaijan for 2024 were not available at the time of the study, the inclusion of 2024 indicators for Ukraine reflects only the continued financial reporting of Myronivsky Hliboproduct and does not imply cross-country comparison for that year. Despite fluctuations, the company shows steady revenue growth – from USD 2,056 million in 2019 to USD 3,046 million in 2024, reflecting expanded production and export capacities. Profitability has been volatile, with positive financial outcomes in 2019 and 2021, followed by losses in 2020 and 2022, largely due to the pandemic and war. Nevertheless, the company's assets have increased, indicating investment in production expansion and modernization, including automated quality control and digital technologies.

Table 4. Key financial indicators of MHP, 2019 ÷ 2024 (million USD).
Tabela 4. Kluczowe wskaźniki finansowe MHP w latach 2019 ÷ 2024 (w mln USD).

Indicator	2019	2020	2021	2022	2023	2024
Revenue	2,056	1,911	2,372	2,642	3,021	3,046
Profit	215	-133	393	-231	142	144
Assets	2,509	2,108	4,014	3,809	3,886	4,426
Capital	1,596	1,254	1,794	1,446	1,567	1,966

Explanatory notes / Objaśnienia: compiled by the authors based on Myronivsky Hliboproduct [24] / zebrane przez autorów na podstawie Myronivsky Hliboproduct [24]

In 2024, Myronivsky Hliboproduct [24] procured equipment for automated poultry carcass analysis (worth over UAH 18 million ($429,696.82)) and sensor modules for the Smart Technologist system. In the same year, the enterprises that had implemented AQS (automated quality systems) experienced an average export growth of 8.5 %, while the number of returns dropped by 31 % compared to 2022.

Both Azersun Holding and Myronivsky Hliboproduct have achieved significant economic results by implementing automated quality control systems and digital technologies, which contributed to lower production costs, reduced defect rates and enhanced process efficiency. The adoption of AQS enabled Azersun to maintain sustained revenue and capital growth, while significantly reducing its environmental impact, thereby reinforcing its market position in the CIS, Middle East and Central Asia. Meanwhile, MHP, despite financial instability caused by the pandemic and geopolitical unrest, has shown consistent revenue growth and expanded export potential by optimizing production and enhancing resilience through digital innovation. Thus, the integration of modern automated and digital systems directly influences improved operational efficiency, higher product quality and the creation of sustainable competitive advantages in diverse economic and geographic contexts. Comparing tender and investment data with the company cases of Azersun Holding and MHP revealed a strong positive correlation between increased digital investment in quality control and improved economic performance.

To further improve production efficiency and international competitiveness, both Azersun Holding and MHP should continue enhancing their automated quality control systems in line with current technological trends and the specifics of the food sector. For Azersun Holding, given its high level of automation and business scale, the priority should be the implementation of integrated platforms based on Industrial Internet of Things (IIoT) and machine learning technologies. This would enable real-time tracking of key quality indicators across the entire supply chain – from raw materials to finished goods. Additionally, the company is advised to implement a centralized analytics system capable of forecasting deviations based on historical data, thereby transitioning from reactive to proactive quality management. Azersun would also benefit from certification under international digital standards (e.g. ISO 23412:2020 [34]), which would strengthen trust among external partners and facilitate access to highly regulated markets.

For MHP, already actively deploying digital tools, the next step should be scaling up AI-based and computer vision solutions. Specifically, the development of automated visual quality control systems on packaging and dispatch lines is recommended, as this would help minimize human errors and reduce return rates. Another promising area is the implementation of blockchain modules to ensure full traceability from field to shelf, particularly important under strict international trading standards. Additionally, MHP could focus on automating environmental monitoring and emissions tracking, contributing not only to ESG compliance, but also to greater brand resilience.

Both companies are encouraged to participate more actively in international consortia and research-industry partnerships related to foodtech and digital quality control, and to expand in-house training programs for staff working with high-tech solutions. The enhancement of automated quality control systems should be based not only on technological adoption but also on a comprehensive revision of organisational culture toward continuous improvement and adaptation to global challenges.

For small and medium-sized enterprises (SMEs), the implementation of automated quality control systems entails a number of serious challenges, among which the key ones are high upfront investments, limited technical support resources and a lack of qualified personnel. Moreover, SMEs often face difficulties in integrating new technologies into existing production processes without major downtime or disruption. A lack of experience in digitalization and conservative management practices can delay innovation adoption and hinder the organizational culture’s adaptation to new requirements. All of this necessitates the development of special support programs, tailored solutions and active involvement in training and consulting initiatives to increase the technological maturity of enterprises and ensure their sustainable development.

Discussion

The study revealed that the implementation of automated quality control systems leads to a profound transformation of production approaches. Traditionally, quality control in the food industry has been selective and reactive – that is, errors were identified after the production cycle had been completed. However, modern technological solutions enable continuous, process-integrated control, drastically reducing the likelihood of substandard products reaching the market. This transforms the very understanding of quality control – it ceases to be a separate stage and becomes the foundation of the entire production process, functioning in real time. Liberty et al. [40]

investigated the impact of quality control automation on defect reduction in the food industry in developed economies. They highlighted the significant effect of automated systems, particularly in reducing errors during product packaging and labelling stages. Similarly, according to Hassoun et al. [29], the use of automated solutions considerably reduces human errors and lowers the number of consumer complaints. These findings largely align with the current study, which also noted that automation facilitates a shift to continuous control and defect reduction. However, while previous authors emphasized the limited role of AI, the present research considers AI as a key element for predictive and preventive control.

The implementation of automated solutions requires a restructuring of organizational structures and internal processes. Enterprises must integrate various digital components – such as sensors, software, data storage and processing systems – into a unified ecosystem [16, 39, 52]. This necessitates staff retraining, the redistribution of responsibilities and a strengthened role for IT departments. Additionally, cases were identified where a low level of digital maturity hindered full automation, highlighting the importance of preliminary technological audits and strategic planning. Garcia-Garcia et al. [27] also focused on the transformation of organizational structures and internal business processes in food industry enterprises in the context of automation. Their primary focus was on how automation affects the distribution of managerial functions, interdepartmental interaction and internal decision-making models. In contrast to the present study, which links these transformations to macroeconomic conditions and national strategies, Garcia-Garcia et al. [27] focused mainly on internal organizational changes. However, both studies agree that successful automation is impossible without staff retraining, the adaptation of management practices and improved internal communication flexibility.

The automation of production control has a positive impact on the financial performance of companies [3, 35]. Although initial investments in equipment and software can be substantial, they are offset in the long term by productivity gains, defect reduction and lower costs related to reprocessing or product recalls. There is also reduced demand for manual labor in routine operations, allowing resources to be redirected to more complex and creative tasks. Annosi et al. [8] studied the economic efficiency of digital control platform implementation in agri-food companies. They highlighted the positive effects of integrating sensor systems, but noted that significant financial gains are achievable only in enterprises with a high level of digital maturity. This observation is consistent with the current findings on the need for organizational changes and digital staff training. Unlike Annosi et al. [8], however, the present study additionally identified the influence of government strategies and national programs, emphasizing the importance of the macroeconomic context.

The study by Sharma et al. [56] described the financial performance of food industry enterprises following automation, focusing on the high return on investment due to cost savings and increased export potential. The present conclusions confirm the general trend of economic efficiency, but also emphasize that initial investments require considerable resources and planning – a factor not fully explored in Sharma et al. [56] work.

Special attention in the current study was given to the interaction of various technologies – from machine vision and sensor systems to artificial intelligence elements and digital platforms. The greatest effect is achieved when these technologies are integrated comprehensively, complementing one another and forming a coherent system. Such systems are capable not only of detecting deviations, but also of independently generating corrective actions, forecasting risks and adapting to changing production conditions. Abass et al. [1] focused on the integration of machine vision and AI in food industry quality control. The results demonstrated high defect detection accuracy and real-time automated adjustment of production parameters. According to Kumar et al. [38], the application of machine vision enables rapid response to deviations, minimizes technological losses and reduces costs related to physical inspections. The present study supports this approach, but places greater emphasis on the comprehensive integration of various technologies, including blockchain and IoT.

Even when technologies and resources are available, companies often face institutional constraints. Resistance from staff, conservative management structures and a lack of innovation motivation all hinder the implementation of new solutions. At the industry level, challenges also arise from the absence of unified automation standards and regulatory limitations that fail to keep pace with technological advancement. Rincon-Ballesteros et al. [51] conducted a comparative analysis of automation in companies in Europe and Latin America, highlighting the importance of corporate culture and staff resistance to change. These conclusions fully align with the current study's discussion of institutional barriers and the need to address resistance. However, Rincon-Ballesteros et al. focused more on the cultural specifics of different countries.

The macroeconomic and political context has proven to be a significant factor influencing the pace and scale of automation. In countries where industrial digitalization is enshrined in national strategies and supported by the state, the adoption of modern systems is more active. Modernization programs, subsidies, tax incentives and institutional support from public authorities all contribute to the development of digital solutions in the agri-food sector. Alnoor et al. [7] examined the impact of national digitalization programs on food industry development. They noted that strategic documents and government support play a key role in driving digital transformation. This observation is consistent with the present analysis of national strategy influence, although the current study also highlights the importance of international cooperation and knowledge exchange.

Finally, the analysis confirmed that the potential of automation is far from exhausted. Of particular importance are predictive analytics technologies based on machine learning, as well as the development of industrial networks and distributed blockchain-based systems. The implementation of such solutions can provide not only technical, but also strategic quality control, including full supply chain traceability and adaptation to market fluctuations. Shahbazi and Byun [54] also focused on the future of automated quality systems using predictive analytics and blockchain to ensure supply chain transparency. Shahbazi and Byun’s [54] results highlighted the promise of these technologies, aligning with the current study’s conclusions about the need to continue improving automation and advancing analytical systems. However, in contrast to the present work, Shahbazi and Byun [54] focused on specific case studies of global suppliers.

The analysis confirms that the introduction of automated quality control systems in the food industry has a comprehensive positive impact on production processes, management approaches and the strategic development of enterprises. The results demonstrate the importance of technological integration, organizational readiness and government support. The greatest effectiveness is achieved through a systematic approach that combines digitalization, staff training and sustainable corporate transformation. Thus, automation not only improves product quality, but also becomes a catalyst for deeper modernization of the industry.

Conclusions

1. The implementation of automated quality control systems in the food industry represents a fundamental shift from selective, retrospective monitoring to continuous, preventive quality management that integrates across the entire production cycle. This study's analysis of leading enterprises in Azerbaijan and Ukraine, specifically Azersun Holding and Myronivsky Hliboproduct, demonstrates that the adoption of AQCS, including machine vision, sensor networks, AI-powered analytics and integration with digital platforms such as ERP and MES, yields measurable economic benefits. Azersun Holding achieved revenue growth from 1,003 million to 1,810 million manats (2019-2023), while reducing customer complaints by 42 % and increasing exports by 17 % in 2024. Similarly, MHP's revenue expanded from 2,056 million to 3,046 million USD (2019-2024), despite facing significant external challenges including the COVID-19 pandemic and military conflict, with export growth of 8.5 % and a 31 % reduction in product returns following AQCS implementation. These outcomes confirm that automation not only enhances operational efficiency through reduced defect rates, lower energy consumption and minimized

human errors, but also strengthens competitive positioning by enabling compliance with international standards such as ISO 22000:2018 and FSSC 22000, thereby facilitating market access and building trust among international partners.

2. The practical significance of these findings extends beyond large enterprises to inform strategic decision-making across the food sector. The research identifies critical success factors including comprehensive technology integration, organizational readiness through staff retraining and supportive macroeconomic policy frameworks – as evidenced by Azerbaijan's "digiMATE" program (11.8 million manats in 2024) and Ukraine's increased public procurement of quality control equipment (487 million UAH in 2024, up 19.6 % from 2023). One limitation of the study is its focus on large companies and developed countries, which may not fully reflect the conditions of small and medium-sized enterprises (SMEs) in developing regions. Future research should conduct an in-depth analysis of quality automation implementation in smaller enterprises and explore the impact of emerging technologies such as AI and blockchain on the sustainability of the food industry.

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EFEKTYWNOŚĆ EKONOMICZNA ZAUTOMATYZOWANYCH SYSTEMÓW KONTROLI JAKOŚCI W PRZEMYŚLE SPOŻYWCZYM

S t r e s z c z e n i e

Wprowadzenie. Celem niniejszego badania jest analiza wpływu wdrożenia zautomatyzowanych systemów kontroli jakości na efektywność ekonomiczną przedsiębiorstw z sektora spożywczego. Ramy metodologiczne łączą kompleksową analizę aspektów produkcyjnych, technologicznych i ekonomicznych wdrażania rozwiązań zautomatyzowanych, w tym elementów sztucznej inteligencji, wizji maszynowej, systemów sensorycznych oraz integracji z platformami cyfrowymi. Szczególną uwagę poświęcono doświadczeniom Azersun Holding (Azerbejdżan) i Myronivsky Hliboproduct (Ukraina).

Wyniki i wnioski. W Azersun wdrożenie korporacyjnej platformy cyfrowej objęło ponad 30 przedsiębiorstw, w tym dwa zakłady spożywcze i sieci handlowe, umożliwiając scentralizowane zarządzanie i poprawę dokładności planowania. Przychody firmy wzrosły z 1003 mln do 1810 mln manatów w latach 2019 ÷ 2023. Firma Myronivsky Hliboproduct wdrożyła wirtualnego technologa opartego na sztucznej inteligencji oraz zautomatyzowaną chłodnię o pojemności 20 300 palet z cyfrowym zarządzaniem, co pozwoliło obniżyć koszty energii o 30 % i poprawić dokładność kontroli temperatury. Przychody firmy wzrosły z 2056 mln do 3046 mln dolarów w latach 2019 ÷ 2024, pomimo kryzysów, takich jak pandemia i konflikt zbrojny. Wyniki potwierdzają, że wdrożenie zautomatyzowanych systemów kontroli jakości przekształca system zapewnienia jakości z selektywnego i retrospektywnego w ciągły i prewencyjny, zwiększając efektywność zarządzania, zmniejszając liczbę usterek i wzmacniając zaufanie partnerów międzynarodowych. Praktyczne znaczenie tych badań leży w ich przydatności dla producentów żywności, inżynierów procesowych i menedżerów w zakresie wyboru i wdrażania efektywnych rozwiązań z zakresu zautomatyzowanej kontroli jakości w celu zwiększenia konkurencyjności i zgodności z międzynarodowymi standardami.

Słowa kluczowe: technologie cyfrowe, produkcja przemysłowa, zrównoważony rozwój, integracja technologiczna, wyniki finansowe