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Digital transformation and agricultural competitiveness in Central Asia: A comparative empirical analysis

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Abstract. Digital transformation has become a key driver of agricultural development in Central Asia, where enhancing the competitiveness of the agricultural sector is of strategic importance for ensuring sustainable economic growth and food security. This study aimed to assess the relationship between digitalisation and agricultural competitiveness through a comparative analysis of Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan. The empirical analysis was based on statistical data for the period 2010-2023 obtained from the World Development Indicators database, FAOSTAT, and official national statistical sources. To evaluate the study variables, composite indices of digitalisation and agricultural competitiveness were developed using the Min-Max normalisation method. The relationship between the indices was examined using descriptive statistics, comparative cross-country analysis, and Pearson correlation analysis. The findings indicate that digitalisation increased steadily across all four countries, whereas the dynamics of agricultural competitiveness differed substantially. A strong positive correlation between the two indices was identified for Kazakhstan (r = 0.97), Uzbekistan (r = 0.99), and Tajikistan (r = 0.98), while Kyrgyzstan exhibited a strong negative correlation (r = -0.95). The findings suggest that the impact of digitalisation on agricultural competitiveness depends not only on the diffusion of digital technologies but also on the quality of the institutional environment, the structural characteristics of the agricultural sector, and the efficiency of resource utilisation. The novelty of the study lies in the comprehensive assessment of the relationship between digitalisation and agricultural competitiveness in Central Asian countries based on the proposed composite indices, which made it possible to demonstrate that this relationship is shaped by country-specific characteristics of agricultural development. The findings may support the formulation of public policies and digital transformation strategies aimed at improving resource efficiency, strengthening agricultural competitiveness, and promoting the sustainable development of rural areas

Keywords: digitalisation; agricultural competitiveness; Central Asia; information and communication technologies; digital transformation; Pearson correlation analysis

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Introduction

Digital transformation has become one of the main drivers of efficiency, resilience, and competitiveness in agrifood systems worldwide. As noted by R. Birner *et al.* (2021), digital technologies are increasingly reshaping agrifood systems by improving productivity, strengthening resilience, and enhancing the overall competitiveness of the agricultural sector. R. Abbasi *et al.* (2022) further emphasised that advances in information and communication technologies, artificial intelligence, big data analytics, the Internet of Things, and digital platforms create new opportunities for modernising agriculture, improving the management of land, water, and labour resources, and enhancing decision-making processes. Against the backdrop of climate change, growing global food demand, and the need for sustainable rural development, digital technologies are increasingly recognised not only as instruments of technological modernisation but also as key enablers of productivity growth, food security, and long-term agricultural competitiveness.

For the countries of Central Asia, the adoption of digital technologies is of strategic importance, as agriculture remains a major source of employment, rural household income, and food security. According to S. Wang *et al.* (2025), the region has experienced steady progress in digital infrastructure development, expanded access to information and communication technologies, and the gradual adoption of digital solutions across the agrifood sector. A. Kadyraliev *et al.* (2024) demonstrated that the application of digital technologies and automated management systems improves the efficiency of agricultural management in the Kyrgyz Republic. Taken together, these studies suggest that digital technologies contribute to higher agricultural productivity, improved management practices, reduced production risks, and more sustainable agricultural development. However, the pace of digital technology adoption, the quality of the institutional environment, and the progress of digital transformation differ considerably across Central Asian countries, highlighting the need for comparative analysis. S. Wang *et al.* (2025) highlighted that recent research has increasingly shifted from examining individual digital technologies to assessing their broader impact on the resilience and competitiveness of agrifood systems, with particular attention devoted to the effects of digitalisation on agricultural productivity, resource-use efficiency, value chain resilience, human capital development, and public governance. Similarly, R. Abbasi *et al.* (2022) concluded that digital transformation promotes economic efficiency, accelerates innovation, strengthens the adaptive capacity of the agricultural sector, and supports its long-term sustainable development.

Despite the growing body of research on digital transformation in agriculture, several important issues remain insufficiently explored. Most existing studies focus on individual countries, specific digital technologies, or particular areas of their application. Comparative analyses covering Central Asian countries remain limited, while the relationship between digital development and agricultural competitiveness has rarely been examined using composite indicators that enable consistent cross-country comparisons. Although the countries of Central Asia share a common historical background, they differ substantially in their levels of digital development, institutional quality, and the pace of agricultural modernisation. These differences underscore the need for an integrated analytical framework capable of assessing the relationship between digital development and agricultural competitiveness across the region. Accordingly, the present study aimed to assess the relationship between digital development and agricultural competitiveness in the countries of Central Asia through a comparative analysis.

Literature Review

Agriculture has traditionally played an important role in the economies of Central Asian countries; however, its contribution to gross domestic product (GDP) varies considerably across the region. According to the World Development Indicators (World Bank, 2024), agriculture accounts for less than 5% of GDP in Kazakhstan, whereas its contribution remains substantially higher in Kyrgyzstan and Uzbekistan despite a gradual decline over the study period. Tajikistan exhibits the highest dependence on agriculture, with the sector consistently contributing more than 20% of national GDP. These differences reflect variations in economic structure, the pace of industrialisation, and natural resource endowments, creating distinct conditions for digital transformation and the development of agricultural competitiveness.

The literature considers agriculture in Central Asia not only as a productive sector but also as a key driver of regional socio-economic development. R. Pomfret (2019) argues that improvements in agricultural productivity contribute to higher labour productivity, rural development, and better living standards for rural populations. Similarly, the World Bank (n.d.) emphasises that agriculture continues to play a crucial role in employment generation and rural household income despite its declining share in GDP across the region. Over the past decade, growing attention has been devoted to the role of digital technologies in transforming agrifood systems. S. Wolfert *et al.* (2017) were among the first to demonstrate that precision agriculture, big data analytics, and digital platforms improve farm management and enhance resource-use efficiency. Expanding this perspective, B. Basso & J. Antle (2020) argued that digital agriculture represents an essential pathway toward the design of sustainable agrifood systems by simultaneously improving productivity and environmental

sustainability. J.C. Aker (2011) showed that information and communication technologies substantially improve farmers' access to information and advisory services, whereas E. Nakasone *et al.* (2014) demonstrated that digital technologies facilitate access to financial services and agricultural markets, thereby reducing transaction costs and increasing the transparency of agrifood value chains.

Despite the considerable potential of digital technologies, recent studies indicate that the effectiveness of digital transformation depends on more than technological progress alone. L. Klerkx *et al.* (2019) emphasise the importance of institutional quality, infrastructure development, and agricultural knowledge and advisory systems in facilitating the adoption of digital innovations. R. Birner *et al.* (2021) further argue that successful digital transformation depends largely on human capital, institutional capacity, and farmers' ability to adapt to emerging technologies. These findings suggest that, particularly in emerging and transition economies, the outcomes of digital transformation are shaped by the interaction of technological, institutional, and organisational factors.

Although research on agricultural digital transformation has expanded rapidly in recent years, empirical evidence remains concentrated on either developed economies or individual developing countries. Comparative studies focusing on Central Asia are still limited. Moreover, existing research has primarily examined specific dimensions of digitalisation, including information and communication technologies, digital infrastructure, and individual digital solutions, whereas comprehensive assessments of the relationship between digital development and agricultural competitiveness remain scarce. Cross-country differences in this relationship, particularly those associated with institutional quality, agricultural structure, and the level of digital maturity, have received limited scholarly attention. These research gaps provide the rationale for the present study, which evaluates the relationship between digital development and agricultural competitiveness across Central Asian countries using composite indices.

Materials and Methods

Data sources. The empirical analysis was based on statistical data for four Central Asian countries – Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan – covering the period from 2010 to 2023. These countries were selected because they share a common historical background, similar institutional settings, and a significant role of agriculture in their national economies, thereby ensuring the comparability of the cross-country analysis. The study draws on data from the World Development Indicators (World Bank, n.d.) database, FAOSTAT (FAO, n.d.), and official publications of the national statistical agencies of the selected countries. The World Development Indicators database was used to construct the digitalisation index, while FAOSTAT provided the agricultural indicators used to develop the agricultural competitiveness index. National statistical sources were employed to verify and complement selected statistical indicators. The use of internationally comparable statistical data ensures the reliability of cross-country comparisons of digitalisation and agricultural competitiveness. The study covers the period from 2010 to 2023 because, at the time of the analysis, internationally comparable data for all selected indicators were consistently available for all four countries only up to 2023. Data for 2024-2025 have been released at different times by international organisations and national statistical agencies, preventing their consistent use in a comparative cross-country analysis.

Construction of the Digitalisation Index (DI). To quantify the level of digitalisation, a Digitalisation Index was developed by combining indicators that characterise digital infrastructure and the diffusion of information and communication technologies. The conceptual framework of the Digitalisation Index was based on internationally recognised approaches to measuring digital development, particularly the ICT Development Index (IDI) developed by the International Telecommunication Union (ITU, 2017) and the methodological principles for constructing composite indicators presented in the OECD Handbook on Constructing Composite Indicators (OECD & Joint Research Centre of the European Commission, 2008). These frameworks identify Internet connectivity, access to communication infrastructure, and broadband development as the core dimensions of national digital development. Rather than reproducing the original international indices, the present study adapted their conceptual principles to the objectives of a comparative assessment of digitalisation in the agricultural sector of Central Asian countries.

The selection of indicators was additionally guided by OECD & Joint Research Centre of the European Commission (2008), which recommends that composite indicators should be based on conceptually relevant, statistically reliable, and internationally comparable variables. Because not all indicators included in the original ITU methodology were consistently available for all four countries throughout the entire study period (2010-2023), only indicators meeting these methodological requirements and ensuring complete cross-country comparability were retained. The indicators were selected based on three criteria: their relevance to the research objectives, their ability to capture key dimensions of digital development, and the availability of internationally comparable data for all four countries throughout the study period. The index was constructed by aggregating normalised indicators into a composite measure following the approach commonly applied in the development of composite digitalisation indices. This approach ensures the comparability of indicators expressed in different units of measurement.

The Digitalisation Index includes the following indicators: Internet users (% of the population); Mobile cellular subscriptions (per 100 inhabitants); Fixed broadband subscriptions (per 100 inhabitants). Together, these indicators provide a comprehensive assessment of the level of digital development in the countries under study. To ensure cross-country comparability, all variables were normalised using the Min-Max normalisation method. Min-Max normalisation ensured the comparability of indicators measured in different units. The Digitalisation Index was calculated as the arithmetic mean of the normalised indicators:

$$X_{ij}^{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}, \quad (1)$$

where digitalisation Index for country *j*; number of indicators included in the index; normalised value of indicator *i* for country *j*.

Following the methodological guidance presented in the OECD Handbook on Constructing Composite Indicators (OECD & Joint Research Centre of the European Commission, 2008), equal weights were assigned to all indicators because no robust theoretical or empirical evidence justified differential weighting. This approach enhances methodological transparency, ensures the consistency and comparability of the composite index across countries, and reduces potential bias associated with subjective weighting schemes.

Construction of the Agricultural Competitiveness Index (ACI). To assess the level of agricultural competitiveness, a Composite Agricultural Competitiveness Index (ACI) was developed. The conceptual framework of the Agricultural Competitiveness Index was informed by the multidimensional concept of agricultural competitiveness proposed by L. Latruffe (2010) and the Food and Agriculture Organisation of the United Nations (FAO, 2017). These approaches consider agricultural competitiveness as a multidimensional concept that should be assessed through a combination of indicators reflecting the economic contribution of agriculture, production efficiency, productivity, and export performance rather than by a single measure.

In this study, agricultural competitiveness is defined as a multidimensional concept reflecting the economic performance of the agricultural sector. Following these methodological principles, the composite index was designed to capture the principal dimensions of agricultural competitiveness while ensuring international comparability and consistent data availability for all four Central Asian countries throughout the study period. The selected indicators were chosen because they collectively reflect the sector's contribution to the national economy, production efficiency, export capacity, and labour productivity, which are widely recognised as key dimensions of agricultural competitiveness. The selection of indicators was guided by the need to provide a comprehensive assessment of agricultural competitiveness and covers the key dimensions of the sector, including its contribution to the national economy, production efficiency, export performance, and labour productivity. Collectively, these indicators provide a comprehensive assessment of agricultural competitiveness and enable meaningful cross-country comparisons.

The Agricultural Competitiveness Index comprises the following indicators: Agriculture, forestry, and fishing, value added (% of GDP); Crop yield (t/ha); Agricultural exports (million USD); Agricultural labour productivity (agriculture, forestry, and fishing value added per worker, constant 2015 USD). All indicators were normalised using the Min-Max normalisation method and aggregated into a composite index:

$$ACI_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij}^{norm}, \quad (2)$$

where ACI_j – Agricultural Competitiveness Index for country *j*; *n* – number of indicators included in the index; X_{ij}^{norm} – normalised value of indicator *i* for country *j*.

Following the methodological guidance provided in (OECD & Joint Research Centre of the European Commission, 2008), equal weights were assigned to all indicators because no robust theoretical or empirical evidence justified differential weighting. This approach enhances methodological transparency, ensures the consistency and comparability of the composite index across countries, and reduces potential bias associated with subjective weighting schemes.

Data analysis. The empirical analysis was conducted in three stages. First, the dynamics of the Digitalisation Index and the Agricultural Competitiveness Index were analysed over the period 2010-2023. Second, a comparative cross-country analysis was carried out to identify differences in the levels of digital development and agricultural competitiveness among the Central Asian countries. Third, the relationship between digitalisation and agricultural competitiveness was assessed using the Pearson correlation coefficient:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}}, \quad (3)$$

where *r* – Pearson correlation coefficient; *x* – Digitalisation Index (DI); *y* – Agricultural Competitiveness Index (ACI); $\bar{x}$ – mean value of the Digitalisation Index; $\bar{y}$ – mean value of the Agricultural Competitiveness Index. The Pearson correlation coefficient was employed to evaluate the strength and direction of the linear relationship between the Digitalisation Index and the Agricultural Competitiveness Index. The estimated correlation coefficients describe the statistical association between the two indices and should not be interpreted as evidence of a causal relationship.

Study limitations. Despite the methodological robustness of the proposed approach, several limitations

should be considered when interpreting the findings. First, the Min-Max normalisation method is sensitive to extreme values, which may influence the resulting composite index scores. Second, equal weights were assigned to all indicators when constructing the composite indices. Although this approach ensures methodological transparency and facilitates cross-country comparability, it does not account for potential differences in the relative importance of individual indicators. Third, the analysis is based on aggregated macroeconomic data, which limits the ability to capture regional disparities within individual countries and sector-specific characteristics of agricultural production. Fourth, Pearson correlation analysis identifies statistical associations between digitalisation and agricultural competitiveness but does not establish causal relationships between the variables. Finally, the study covers the period from 2010 to 2023 because, at the time of the analysis, internationally comparable data for all selected indicators were consistently available for all four countries only up to 2023. Data for 2024-2025 had not yet been released simultaneously by international organisations and national statistical agencies, preventing their inclusion in a consistent cross-country analysis.

Results

Dynamics of digitalisation in Central Asia

The analysis of the Digitalisation Index revealed a steady increase in the level of digitalisation across all Central Asian countries during the period 2010-2023. Despite this overall upward trend, the pace and extent of digital transformation differed substantially among the countries under study. These differences reflect the heterogeneous nature of digitalisation processes across the region, as well as variations in digital infrastructure development and the adoption of information and communication technologies. Table 1 presents the calculated values of the Digitalisation Index.

Table 1. Digitalisation Index in Central Asia, 2010-2023

Year	Kazakhstan	Kyrgyzstan	Uzbekistan	Tajikistan
2010	0.37	0.17	0.13	0.09
2011	0.42	0.20	0.15	0.11
2012	0.47	0.23	0.18	0.13
2013	0.52	0.27	0.21	0.16
2014	0.57	0.31	0.26	0.19
2015	0.66	0.32	0.30	0.20
2016	0.69	0.35	0.33	0.22
2017	0.71	0.39	0.36	0.24
2018	0.73	0.43	0.40	0.27
2019	0.75	0.48	0.44	0.30
2020	0.77	0.52	0.47	0.33
2021	0.79	0.57	0.50	0.36
2022	0.80	0.62	0.55	0.39
2023	0.81	0.67	0.62	0.46

Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

Throughout the study period, Kazakhstan maintained the highest level of digitalisation among the four countries. The Digitalisation Index increased from 0.37 in 2010 to 0.81 in 2023, representing more than a twofold increase over the initial level. This trend reflects the continuous development of digital infrastructure and the rapid adoption of information and communication technologies. Kyrgyzstan and Uzbekistan also recorded substantial progress in digitalisation over the study period. In Kyrgyzstan, the Digitalisation Index increased from 0.17 to 0.67, while in Uzbekistan it rose from 0.13 to 0.62, indicating continued improvements in digital infrastructure and wider adoption of digital technologies. However, the trajectories of digitalisation differed between the two countries. In Uzbekistan, the index increased at a relatively steady pace throughout the study period, whereas in Kyrgyzstan the most pronounced growth occurred after 2015, which may reflect the acceleration of digital transformation and broader access to information and communication technologies.

Although Tajikistan consistently recorded the lowest Digitalisation Index among the Central Asian countries throughout the study period, its index increased from 0.09 in 2010 to 0.46 in 2023. This trend indicates gradual improvements in digital infrastructure and the increasing adoption of digital technologies. The remaining gap relative to the other countries highlights the need for further investment in digital infrastructure and improved access to digital services. Figure 1 illustrates the dynamics of the Digitalisation Index across the four Central Asian countries during 2010-2023.

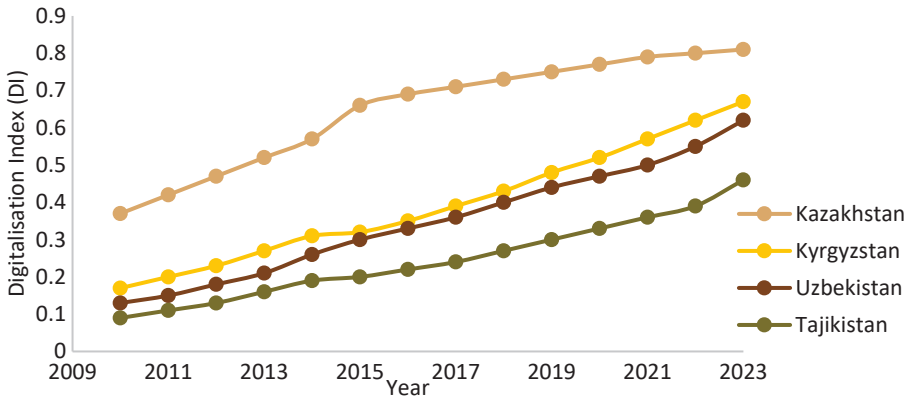

Figure 1. Dynamics of the Digitalisation Index in Central Asia, 2010-2023
Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

Overall, the analysis indicates that, despite the steady progress in digitalisation across all Central Asian countries, the pace of digital transformation differed substantially, resulting in persistent cross-country disparities in the level of digital development.

Trends in agricultural competitiveness

The analysis of the Agricultural Competitiveness Index revealed substantial differences in both the level and dynamics of agricultural competitiveness across the Central Asian countries. Although several countries exhibited improvements in agricultural performance during the study period, the trajectories of the ACI differed considerably, reflecting differences in the effectiveness of agricultural development and structural characteristics of the sector. The calculated values of the Agricultural Competitiveness Index are presented in Table 2.

Table 2. Agricultural Competitiveness Index in Central Asia, 2010-2023

Year	Kazakhstan	Kyrgyzstan	Uzbekistan	Tajikistan
2010	0.24	0.30	0.55	0.28
2011	0.27	0.29	0.56	0.28
2012	0.29	0.29	0.58	0.28
2013	0.29	0.29	0.59	0.29
2014	0.31	0.28	0.59	0.29
2015	0.29	0.27	0.59	0.30
2016	0.29	0.27	0.59	0.30
2017	0.31	0.27	0.60	0.31
2018	0.31	0.26	0.61	0.32
2019	0.33	0.26	0.62	0.32
2020	0.35	0.26	0.63	0.33
2021	0.38	0.26	0.65	0.34
2022	0.40	0.23	0.66	0.34
2023	0.42	0.20	0.67	0.35

Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

Uzbekistan consistently recorded the highest ACI values throughout the study period. The index increased from 0.55 in 2010 to 0.67 in 2023, indicating a gradual strengthening of agricultural competitiveness. Minor fluctuations observed during the study period suggest the stability of key indicators reflecting agricultural productivity and export performance. Kazakhstan also exhibited a steady upward trend in the Agricultural Competitiveness Index, particularly after 2016. Over the study period, the index increased from 0.24 to 0.42, indicating a gradual improvement in agricultural competitiveness.

Tajikistan likewise demonstrated positive growth, with the ACI increasing from 0.28 in 2010 to 0.35 in 2023. Although the rate of growth was more moderate than in Kazakhstan and Uzbekistan, the observed trend indicates a gradual improvement in agricultural competitiveness. At the same time, the relatively low index values point to persistent constraints related to resource-use efficiency and export performance while also indicating considerable potential for further sectoral development.

Unlike the other countries in the region, Kyrgyzstan exhibited a declining trend in the Agricultural Competitiveness Index. During the study period, the index decreased from 0.30 in 2010 to 0.20 in 2023, indicating a deterioration in the composite assessment of agricultural competitiveness despite continued

progress in digital infrastructure development. Figure 2 illustrates the differences in the dynamics of the Agricultural Competitiveness Index across the Central Asian countries.

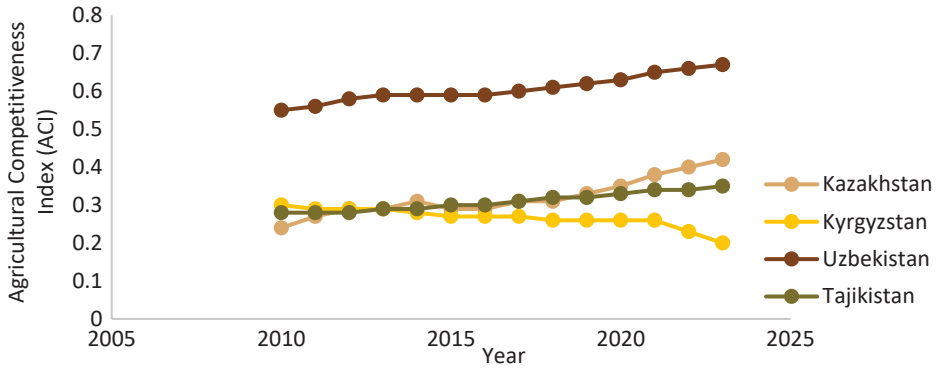

Figure 2. Dynamics of the Agricultural Competitiveness Index in Central Asia, 2010-2023
Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

Overall, the analysis revealed substantial cross-country differences in the dynamics of agricultural competitiveness. While Kazakhstan, Uzbekistan, and Tajikistan experienced increases in the Agricultural Competitiveness Index, Kyrgyzstan recorded a decline. These findings indicate that agricultural development in Central Asia does not follow a uniform trajectory and highlight the importance of considering country-specific characteristics when interpreting the relationship between digitalisation and agricultural competitiveness. To provide a more comprehensive explanation of the observed differences in the Agricultural Competitiveness Index, it is necessary to examine the composition of its underlying indicators. A comparison of the average values of the indicators included in the index provides insights into the determinants of agricultural competitiveness in the countries under study and identifies the factors contributing most to cross-country differences (Table 3).

Table 3. Average values of the components of the Agricultural Competitiveness Index in Central Asian countries, 2010-2023

Indicator	Kazakhstan	Kyrgyzstan	Uzbekistan	Tajikistan
Agriculture, forestry, and fishing, value added (% of GDP)	4.43	20.66	27.01	24.02
Cereal yield (kg/ha)	1,005.1	2,689.2	4,828.1	3,127.8
Agricultural exports (million USD)	2,685.7	625.0	3,764.3	474.3
Agricultural labour productivity (USD per worker, constant 2015 prices)	6,664.3	1,470.0	2,112.9	1,400.0

Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

The results presented in Table 3 indicate that agricultural competitiveness in Central Asian countries is shaped by different structural factors. Kazakhstan records the highest level of agricultural labour productivity (USD 6,664.3 per worker) together with a substantial volume of agricultural exports. These indicators reflect more efficient resource utilisation and a stronger export orientation of the agricultural sector despite the relatively small contribution of agriculture to national GDP. Uzbekistan demonstrates the highest values for most components of the Agricultural Competitiveness Index. The country ranks first in the share of agriculture in GDP (27.01%), cereal yield (4,828.1 kg/ha), and agricultural exports (USD 3,764.3 million), indicating that its agricultural competitiveness is supported by multiple complementary factors.

In both Kyrgyzstan and Tajikistan, agriculture continues to play an important role in the national economy. However, relatively low levels of labour productivity and limited export volumes point to structural constraints that continue to limit improvements in agricultural competitiveness. Overall, the cross-country differences observed in the components of the Agricultural Competitiveness Index indicate that agricultural competitiveness depends not only on the scale of agricultural production but also on labour productivity, resource-use efficiency, and export performance. These structural differences provide an important basis for interpreting the cross-country variation in the relationship between digitalisation and agricultural competitiveness discussed in the following section.

Relationship between digitalisation and agricultural competitiveness

To assess the relationship between digitalisation and agricultural competitiveness, a Pearson correlation

analysis was performed using the Digitalisation Index and the Agricultural Competitiveness Index for the Central Asian countries. The graphical representation of the observed relationships is presented in Figure 3.

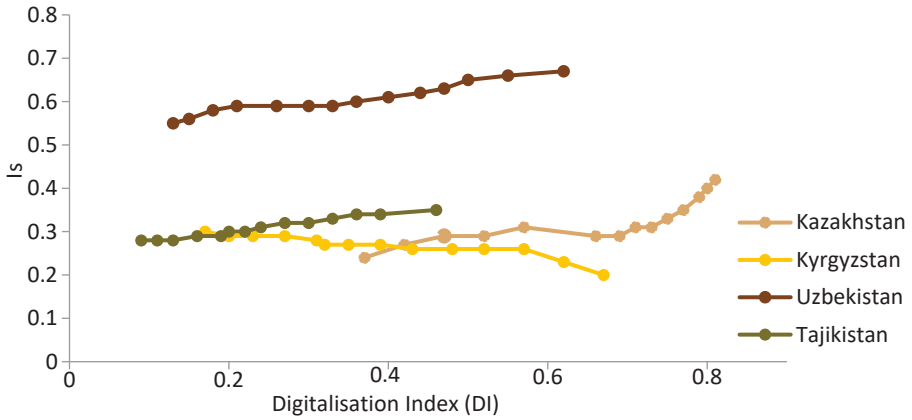

Figure 3. Relationship between digitalisation and agricultural competitiveness in Central Asia, 2010-2023
Source: compiled by the authors based on World Bank (n.d.), FAO (n.d.)

The analysis revealed substantial cross-country differences in both the direction and strength of the relationship between digitalisation and agricultural competitiveness. In Kazakhstan, a very strong positive correlation was observed between the Digitalisation Index and the Agricultural Competitiveness Index ($r \approx 0.97$), indicating a high degree of consistency between digital development and improvements in agricultural competitiveness. However, this relationship is correlational and should not be interpreted as evidence of causality. Similarly strong positive correlations were observed in Uzbekistan ($r \approx 0.99$) and Tajikistan ($r \approx 0.98$). These high correlation coefficients indicate that improvements in digitalisation were accompanied by higher levels of agricultural competitiveness over the study period. Nevertheless, these relationships should also be interpreted as statistical associations rather than evidence of causal effects.

In contrast, Kyrgyzstan exhibited a strong negative correlation between the Digitalisation Index and the Agricultural Competitiveness Index ($r \approx -0.95$). This indicates that, during the study period, progress in digitalisation was accompanied by a decline in the composite measure of agricultural competitiveness. This pattern may reflect a structural mismatch between digital transformation processes and the development of the agricultural sector. As with the other countries, this finding reflects a statistical relationship and does not imply causality.

The Pearson correlation coefficients obtained for the four countries were as follows: Kazakhstan: $r \approx 0.97$; Kyrgyzstan: $r \approx -0.95$; Uzbekistan: $r \approx 0.99$; Tajikistan: $r \approx 0.98$. The correlation coefficients should be interpreted as measures of the strength and direction of the statistical association between the variables and do not imply statistical significance or causal relationships. Overall, the correlation analysis demonstrates that the relationship between digitalisation and agricultural competitiveness varies substantially across the Central Asian countries. These cross-country differences underscore the importance of considering national socio-economic and institutional conditions when interpreting the role of digitalisation in agricultural development.

Discussion

The findings of this study demonstrate that the relationship between digitalisation and agricultural competitiveness is heterogeneous across the Central Asian countries. These findings are consistent with those reported by R. Amoussouhoun *et al.* (2024) and L. Klerkx *et al.* (2019), who argue that the effectiveness of digital transformation depends not only on the level of information and communication technology infrastructure but also on the quality of the institutional environment, the availability of digital services, and farmers' readiness to adopt innovative technologies. The strong positive relationship observed in Kazakhstan may be explained by the country's relatively advanced digital infrastructure, consistent public policies supporting digital transformation, and a higher level of technological modernisation in the agricultural sector. Similar conclusions were reported by N.M. Trendov *et al.* (2019), who demonstrated that digital technologies improve farmers' access to information, financial services, and agricultural markets. These findings suggest that digitalisation should be viewed as an enabling factor for improving agricultural performance, provided that appropriate institutional and economic conditions are in place. Furthermore, digital technologies contribute to lower transaction costs, greater market transparency, and more efficient information systems (Nakasone *et al.*, 2014).

The positive relationship between digitalisation and agricultural competitiveness observed in Uzbekistan and Tajikistan is likely to reflect the gradual

development of the digital environment and the expanding adoption of digital technologies in agriculture. This interpretation is supported by R. Fabregas *et al.* (2019), who showed that digital technologies enhance agricultural productivity, resilience, and production efficiency in developing countries, particularly where access to information and modern agricultural technologies is limited. At the same time, the effectiveness of digital transformation depends on the availability of innovation infrastructure, access to agricultural advisory services, and the effectiveness of institutional support mechanisms for farmers (Fielke *et al.*, 2020). Previous studies have also shown that the adoption of digital technologies in agriculture is constrained by high implementation costs, insufficient digital infrastructure, and limited digital literacy among farmers (Dibbern *et al.*, 2024). These constraints remain relevant for the countries of Central Asia, where agricultural digitalisation is progressing at different rates. Similar observations have been reported in studies of Kyrgyzstan, emphasising that the successful adoption of digital technologies depends largely on improvements in the regulatory framework, the development of institutional support mechanisms, and the implementation of coherent public policies for agricultural digital transformation (Dzhumagulov & Mistriukova, 2025).

The identification of a negative relationship between digitalisation and agricultural competitiveness in Kyrgyzstan represents one of the principal findings of this study. However, this relationship should not be interpreted as evidence that digital development has an adverse effect on the agricultural sector. Rather, it is more likely to reflect a structural mismatch between the expansion of digital infrastructure and the effective adoption of digital technologies in agricultural production. Several factors may explain this pattern. First, digital services in Kyrgyzstan remain concentrated primarily in urban areas, whereas rural regions, where most agricultural production takes place, have more limited access to modern digital infrastructure and digital services (National Statistical Committee of the Kyrgyz Republic, 2024). Second, the predominance of small and medium-sized farms constrains the adoption of capital-intensive digital technologies. Third, institutional constraints, insufficiently developed agricultural advisory services, and limited access to financial resources may further hinder the diffusion of digital innovations in agriculture. These findings suggest that investments in digital infrastructure should be complemented by institutional reforms, strengthened agricultural extension services, and capacity-building initiatives to facilitate the effective adoption of digital technologies in agriculture. These findings are consistent with previous studies demonstrating that the effectiveness of digital transformation is shaped by a combination of socio-economic, institutional, and behavioural factors (Cui & Wang, 2023). In many developing countries, digital infrastructure has expanded more rapidly in urban areas than in rural regions, limiting the practical benefits of digital technologies for agricultural development (Birner *et al.*, 2021). Furthermore, the success of digital transformation depends on human capital, institutional quality, and farmers' capacity to adopt and effectively use new technologies (Rotz *et al.*, 2019).

Farmer digital literacy and effective knowledge transfer mechanisms also play an important role. Previous studies have shown that digital skills, agricultural advisory services, and efficient agricultural knowledge systems are critical for the successful adoption of innovation (Rose & Chilvers, 2018; Ingram & Maye, 2020). In addition, farmers' willingness to adopt digital tools is influenced by their perceived usefulness, trust in new technologies, and access to the necessary financial and technical resources (Diaz *et al.*, 2021). Economic and behavioural factors likewise affect the adoption of digital and financial technologies in agriculture (Sharma *et al.*, 2025). In the absence of these enabling conditions, rapid expansion of digital infrastructure does not necessarily translate into higher agricultural competitiveness.

Conclusions

The findings demonstrate that, despite the overall progress of digital transformation across the Central Asian countries, changes in agricultural competitiveness followed different trajectories. This indicates that there is no universal pattern linking digital transformation to agricultural development. A comparison of the composite indices showed that digital development was accompanied by improvements in agricultural competitiveness in Kazakhstan, Uzbekistan, and Tajikistan, whereas Kyrgyzstan exhibited a negative correlation between the two indicators. The results suggest that the effects of digital transformation depend on country-specific characteristics of the agricultural sector, the quality of the institutional environment, and the capacity to effectively adopt digital technologies. Digital transformation should therefore be regarded as a necessary, but not sufficient, condition for enhancing agricultural competitiveness.

The achievement of positive economic outcomes depends not only on the level of digital development but also on a broader set of institutional, structural, and socio-economic factors, including institutional quality, human capital, access to digital services, and the effectiveness of digital technology adoption mechanisms. The proposed framework for assessing digital development and agricultural competitiveness expands the possibilities for comparative cross-country analysis by accounting for the specific characteristics of agricultural development. From a practical perspective, the proposed approach can support the design of

public policies for agricultural digital transformation, the development of digital infrastructure programmes, and the improvement of mechanisms for promoting digital technology adoption in Central Asian countries. Future research should extend the geographical scope of the analysis, incorporate panel econometric models, and examine the causal effects of digitalisation on agricultural competitiveness.

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Борбордук Азиядагы айыл чарбасынын атаандаштыкка жөндөмдүүлүгү жана санариптик трансформациясы: салыштырма эмпирикалык талдоо

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Аннотация. Санариптик трансформация Борбордук Азия өлкөлөрүндө айыл чарбасын өнүктүрүүнүн негизги факторлорунун бири болуп калды, анткени агрардык сектордун атаандаштыкка жөндөмдүүлүгүн жогорулатуу туруктуу экономикалык өсүштү жана азык-түлүк коопсуздугун камсыз кылууда стратегиялык мааниге ээ. Изилдөөнүн максаты Казакстан, Кыргызстан, Өзбекстан жана Тажикстандын мисалында санариптештирүү менен айыл чарбасынын атаандаштыкка жөндөмдүүлүгүнүн өз ара байланышын салыштырма талдоонун негизинде баалоо болду. Эмпирикалык талдоо 2010-2023-жылдардагы World Development Indicators маалымат базасынан, FAOSTATтан жана улуттук расмий статистикалык булактардан алынган маалыматтарга негизделди. Изилденип жаткан көрсөткүчтөрдү баалоо үчүн Min-Max нормалдаштыруу ыкмасы аркылуу санариптештирүүнүн жана айыл чарбасынын атаандаштыкка жөндөмдүүлүгүнүн интегралдык индекстери түзүлдү. Индекстердин өз ара байланышы сүрөттөөчү статистиканын, өлкөлөр аралык салыштырма талдоонун жана Пирсондун корреляциялык талдоосунун жардамы менен изилденди. Натыйжалар төрт өлкөнүн тең санариптештирүү деңгээли туруктуу өскөнүн, бирок айыл чарбасынын атаандаштыкка жөндөмдүүлүгүнүн динамикасы олуттуу айырмаланганын көрсөттү. Казакстан (r = 0,97), Өзбекстан (r = 0,99) жана Тажикстан (r = 0,98) үчүн эки индекстин ортосунда күчтүү оң корреляция аныкталса, Кыргызстан үчүн күчтүү терс корреляция (r = -0,95) байкалды. Алынган жыйынтыктар санариптештирүүнүн айыл чарбасынын атаандаштыкка жөндөмдүүлүгүнө тийгизген таасири санариптик технологиялардын жайылышы менен гана эмес, институционалдык чөйрөнүн сапатына, агрардык сектордун түзүмдүк өзгөчөлүктөрүнө жана ресурстарды пайдалануунун натыйжалуулугуна да көз каранды экенин көрсөтөт. Изилдөөнүн илимий жаңылыгы сунушталган интегралдык индекстердин негизинде Борбордук Азия өлкөлөрүндөгү санариптештирүү менен айыл чарбасынын атаандаштыкка жөндөмдүүлүгүнүн өз ара байланышын комплекстүү баалоодо жатат. Бул байланыш ар бир өлкөнүн айыл чарбасын өнүктүрүүдөгү өзгөчөлүктөрүнө жараша өзгөрөрү көрсөтүлдү. Изилдөөнүн жыйынтыктары ресурстарды пайдалануунун натыйжалуулугун жогорулатууга, айыл чарбасынын атаандаштыкка жөндөмдүүлүгүн бекемдөөгө жана айыл аймактарынын туруктуу өнүгүшүн камсыз кылууга багытталган мамлекеттик саясатты жана санариптик трансформация стратегияларын иштеп чыгууда колдонулушу мүмкүн

Негизги сөздөр: санариптештирүү; айыл чарбасынын атаандаштыкка жөндөмдүүлүгү; Борбордук Азия; маалыматтык-коммуникациялык технологиялар; санариптик трансформация; Пирсондун корреляциялык талдоосу

Цифровая трансформация и конкурентоспособность сельского хозяйства в Центральной Азии: сравнительный эмпирический анализ

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Аннотация. Цифровая трансформация стала одним из ключевых факторов развития сельского хозяйства в странах Центральной Азии, где повышение конкурентоспособности аграрного сектора имеет стратегическое значение для обеспечения устойчивого экономического роста и продовольственной безопасности. Целью исследования являлась оценка взаимосвязи между цифровизацией и конкурентоспособностью сельского хозяйства на основе сравнительного анализа Казахстана, Кыргызстана, Узбекистана и Таджикистана. Эмпирический анализ основан на статистических данных за 2010-2023 гг., полученных из базы данных World Development Indicators, FAOSTAT и официальных национальных статистических источников. Для оценки исследуемых переменных были разработаны композитные индексы цифровизации и конкурентоспособности сельского хозяйства с использованием метода нормализации Min-Max. Взаимосвязь между индексами исследовалась с помощью методов описательной статистики, сравнительного межстранового анализа и корреляционного анализа Пирсона. Полученные результаты свидетельствуют о том, что уровень цифровизации во всех четырех странах стабильно возрастал, тогда как динамика конкурентоспособности сельского хозяйства существенно различалась. Сильная положительная корреляция между двумя индексами выявлена для Казахстана (r = 0,97), Узбекистана (r = 0,99) и Таджикистана (r = 0,98), тогда как для Кыргызстана установлена сильная отрицательная корреляция (r = -0,95). Полученные результаты свидетельствуют о том, что влияние цифровизации на конкурентоспособность сельского хозяйства определяется не только распространением цифровых технологий, но и качеством институциональной среды, структурными особенностями аграрного сектора и эффективностью использования ресурсов. Научная новизна исследования заключается в комплексной оценке взаимосвязи между цифровизацией и конкурентоспособностью сельского хозяйства стран Центральной Азии на основе предложенных композитных индексов, что позволило показать обусловленность данной взаимосвязи специфическими особенностями развития сельского хозяйства каждой страны. Результаты исследования могут быть использованы при разработке государственной политики и стратегий цифровой трансформации, направленных на повышение эффективности использования ресурсов, укрепление конкурентоспособности сельского хозяйства и обеспечение устойчивого развития сельских территорий

Ключевые слова: цифровизация; конкурентоспособность сельского хозяйства; Центральная Азия; информационно-коммуникационные технологии; цифровая трансформация; корреляционный анализ Пирсона