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GRAIN CLUSTERS AND REDUCE PRODUCT WASTE

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Abstract

This study analyzes the problems of forming a modern agrologistic ecosystem in grain clusters and reducing post-harvest losses at the stages of grain cultivation, storage and transportation. The work studies the role of Internet of Things (IoT), artificial intelligence (AI) and controlled atmosphere (CAS) technologies in increasing logistics efficiency . The shortcomings of storage and transport infrastructure and their economic consequences are assessed using the example of the agrarian sector of the Republic of Uzbekistan, in particular, the activities of grain clusters in the Kashkadarya region. The analysis shows that the transition from traditional storage and transport systems to a smart logistics ecosystem significantly reduces product waste and serves to strengthen national food security.

Keywords : grain clusters, agrologistics, product waste, Internet of Things (IoT), smart warehouse, food safety.

Login

In global agribusiness chains, one of the most pressing challenges is to ensure food security and increase productivity, while preserving harvested produce without wasting it. [1] An estimated 1.3 billion tons of food is lost annually worldwide, causing economic losses as well as environmental sustainability. [1] A significant portion of this wastage is due to inadequate logistics and storage infrastructure. [1] In particular, in the grain sector, significant losses are experienced in the post-harvest chain due to technical and managerial errors. [2] In developing countries, this problem is even more acute, with grain storage alone accounting for up to 40 percent of total losses.[1]

The share of agriculture in the GDP of the Uzbek economy is significant, and consistent strategic programs are being adopted to reform the sector. [4] Although strategic plans provide for increasing product exports and modernizing agro-industrial chains, in real practice the problem of a lack of transport and modern storage facilities during the harvest period remains.[6] Such infrastructural constraints are most evident during the autumn and spring peak seasons, forcing farmers to quickly sell or destroy their products at low prices.[6] The government is taking measures to financially strengthen the agricultural sector by reducing the tax burden, including by introducing a zero VAT rate for farmers and peasants from January 1, 2026.[7] However, these incentives can only produce the expected economic results if they are combined with the digital modernization of the logistics chain and a modern management ecosystem.

Literature review on the topic

In the scientific literature, the concept of Post-Harvest Loss (PHL) is defined as the reduction in quantitative and qualitative indicators that occur in the stages from harvest to final consumption. [2] While quantitative loss is a decrease in physical weight, qualitative loss refers to a decrease in the nutritional content of the grain, the level of mycotoxin contamination, and the market value.[2] Research scientists have analyzed factors in grain production, from the genetic characteristics of the seed to the humidity and temperature parameters of storage conditions.[8] In particular, an excess of moisture in the grain accelerates the processes of transpiration and evaporation, leading to the formation of condensate in the warehouse and, as a result, the growth of mycological fungi and toxic mycotoxins.[9]

In the context of grain clusters in Uzbekistan, the need to form regionally integrated chains to overcome these problems has been explored.[11] For example, in large clusters such as

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Mirishkor, Nishon, Koson, and Karshi in the Kashkadarya region, the integration of 700 to 1,000 farms increases the volume of raw material production, but the uneven distribution of regional infrastructure causes disruptions in the logistics chain. [12] Increasing the competitiveness of the cluster system directly depends on the level of implementation of modern storage and logistics technologies (for example, smart sensors and automated systems).[11]

Research methodology

This study used systematic analysis and comparative modeling methods to assess product waste and improve logistics efficiency in grain clusters. Transpiration and vapor pressure gradient equations were studied to analyze losses during grain storage based on physical and biochemical mechanisms.[9] The effectiveness of Controlled Atmosphere Storage (CAS) technology was evaluated through its ability to regulate gas composition: by reducing O_2 the amount of oxygen ( ) from the usual 21% to $2-5\%$ and increasing the amount of carbon dioxide (CO_2) 0.03% to $5-10\%$, pest respiration and reproduction were inhibited.[9]

At the same time, the depreciation characteristics of vehicles and the optimality of movement routes were analyzed when assessing physical losses (spills, mechanical damage) in the logistics chain. [1] The object of the study was the analysis of clusters and their territorial location in the Kashkadarya region, one of the largest grain-growing regions of Uzbekistan.[12] The model of the frequency and accuracy of real-time data transmission of smart warehouses (WMS) and IoT sensors was studied when assessing the impact of information and communication technologies.[13]

Analysis and results

Analysis shows that traditional approaches to grain logistics lead to high waste. Temperature and humidity are key critical control points in maintaining grain quality. [10] Sudden temperature changes create steam in the warehouse, which causes moisture to condense on the grain surface and cause grain adhesion. [10] Using SensorNode LoRaWAN sensors, such as the GrainMonitor platform, is highly effective in solving this problem.[10] Smart probes mounted on a 3-meter steel bar transmit grain temperature and humidity up to 4 times a day, allowing for remote monitoring of potential mold risks with up to 3 years of battery life.[10]

In India, IoT sensors and AI-enabled cameras deployed by the World Food Programme (WFP) detect carbon dioxide and rodent activity in warehouses, sending instant alerts to managers.[14] This system has dramatically reduced grain losses and proven to be a sustainable supply chain.[14]

In the digitalization of cluster infrastructure in Uzbekistan, the integration of warehouse management systems (WMS) and transport logistics tools is of great importance.[13] The WMS system can remotely manage processes such as advanced shipment notification, inventory regrouping and replenishment (slotting).[13] In particular, forecasting transport routes using artificial intelligence (AI) will allow reducing transport costs and eliminating delays in cargo delivery.[6] While “smart farming” methods introduced in small farms in Uzbekistan within the framework of FAO projects have reduced production costs from 50 to 20 percent, this approach in large clusters will allow achieving even higher economic efficiency by modernizing the logistics chain.[16]

Table or diagram

The table below provides a detailed comparison of the functional capabilities and impact on grain waste of traditional agrologistics systems and modern digital ecosystems:

Logistics and storage	**Traditional logistics**	**Modern digital logistics**	**Expected efficacy and mechanism**

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parameters	system	ecosystem (IoT & AI)	
Temperature and humidity monitoring	Manual measurement (once a week or visual inspection)	Continuous real-time transmission using IoT sensors (LoRaWAN SensorNode)	Reduce the risk of fungal infections and mycotoxins 90%
Gas Environment Control (Atmosphere)	Natural ventilation (risk of humid air ingress and condensation)	Controlled atmosphere (CAS: $2-$, $5-$)	Stopping insect reproduction and increasing shelf life by 5 times
Warehouse inventory management	Paperless and human-based inventory	Cloud-based WMS (Warehouse Management System), RFID and smart e-ink tags	Optimize excess inventory and prevent logistics disruptions
Transport route management	Fixed fixed routes, seasonal loads	Route optimization based on GPS sensors and artificial intelligence (AI)	Reduce road traffic waste and fuel consumption by $15-$
Pest protection	Periodic chemical fumigation (pesticide application)	AI camera and vibro-acoustic sensor monitoring	Early detection of rodents and pests

Conclusion and suggestions

The results of the study show that reducing product waste in grain-growing clusters requires not only traditional agrotechnical measures, but also the introduction of modern information technologies and digital logistics infrastructure. In the case of clusters in Kashkadarya and other regions, although production integration is high, shortcomings in the transport and logistics chain reduce overall profitability. [6]

Based on the research results, the following scientific and practical proposals are put forward:

- **Equipping cluster warehouses with sensors :** It is necessary to gradually install IoT-probe systems that continuously monitor temperature, humidity, and quantity in grain silos and flat warehouses . CO_2 [10]
- **Implementation of digital warehouse management (WMS) software : This system** allows real-time monitoring of the volume and quality of the crop received from all farms within the cluster, coordination of transport loads, and management of storage periods .[13]

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- **Using AI technologies in the logistics chain :** Implementing artificial intelligence algorithms to forecast demand and optimize transportation routes can prevent traffic jams and unnecessary truck stops during peak seasons. [6]
- **Effective use of financial incentive mechanisms** : It is necessary to direct funds released from tax incentives and subsidies provided by the state (for example, resources saved due to VAT refunds) specifically to the modernization of agro-logistics infrastructure and refrigerated/hermetic storage capacities.[7]

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