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BLOCKCHAIN TECHNOLOGIES IN THE AIC OF THE REPUBLIC OF KAZAKHSTAN: POTENTIAL AND IMPLEMENTATION MECHANISMS

ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ АӨК-ДЕГІ БЛОКЧЕЙН ТЕХНОЛОГИЯЛАРЫ: ЕНГІЗУ ӘЛЕУЕТІ МЕН МЕХАНИЗМДЕРІ

ТЕХНОЛОГИИ БЛОКЧЕЙН В АПК РЕСПУБЛИКИ КАЗАХСТАН: ПОТЕНЦИАЛ И МЕХАНИЗМЫ ВНЕДРЕНИЯ

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Abstract. ***The objective*** **- is to identify the systemic barriers to digital transformation and substantiate ways to overcome them through decentralized data management systems in crop production and livestock farming.** ***Methods*** **– content analysis of global practices for the period 2023–2025 was conducted, and information from state programs and pilot projects on asset tokenization and digital product traceability in the republic was structured to understand current trends and systematize both international and domestic experience.** ***Results*** **– a comprehensive assessment of the integration of blockchain technology into the agro-industrial complex of the Republic of Kazakhstan was carried out, and the main mechanisms for implementing distributed ledger technologies were identified, including the automation of agricultural insurance through meteorological oracles and smart contracts. The feasibility of using a Private Blockchain architecture to maintain a balance between audit transparency and the protection of the commercial confidentiality of agricultural holdings was confirmed. The potential of product «digital passports» for verifying «Halal» and «Organic» standards was demonstrated, which is critical for strengthening the country's export position. The study also presents the synergy between blockchain and IoT solutions for the precise monitoring of carbon footprints within the framework of the Net-Zero strategy. The possibility of digitizing grain warehouse receipts in the Kostanay Region as a tool for reducing transaction costs was examined.** ***Conclusions*** **– the study demonstrates that the application of hybrid blockchain models effectively minimizes information asymmetry and eliminates inefficient intermediary links in agribusiness. The authors theoretically substantiate the necessity of developing a national agrarian blockchain ecosystem as a key element of the country's infrastructure. This digital solution ensures impeccable legal integrity in the registration of land ownership rights and fully automates the process of allocating state budget subsidies. A broad range of opportunities and prospects for cryptographic protocols in the context of mitigating institutional risks is demonstrated, significantly enhancing the long-term investment attractiveness of Kazakhstan's agrarian sector at the international level.**

Аңдатпа. ***Мақсаты*** **— цифрлық түрлендірудің жүйелік кедергілерін анықтау және оларды өсімдік шаруашылығы мен мал шаруашылығындағы деректерді басқарудың орталықтандырылмаған жүйелері арқылы еңсеру жолдарын негіздеу.** ***Әдістері*** **-2023-2025 жылдарға арналған әлемдік тәжірибелердің контент-талдауы, шетелдік және отандық тәжірибені жүйелеу және үрдістерді түсіну үшін республикадағы активтерді токенизациялау және өнімнің цифрлық қадағалануы жөніндегі мемлекеттік бағдарламалар мен пилоттық жобалардан ақпарат құрылымдалған.** ***Нәтижелер*** **- блокчейн технологиясының Қазақстан Республикасының агроөнеркәсіптік кешеніне интеграциялануына кешенді бағалау жүргізілді, метеорологиялық оракулдар мен смарт-келісімшарттар арқылы агросақтандыруды автоматтандыруды қоса алғанда, бөлінген тізілімдерді енгізудің негізгі механизмдері айқындалды. Аудиттің ашықтығы мен агрохолдингтердің коммерциялық құпиясын қорғау арасындағы теңгерімді сақтау үшін Private Blockchain архитектурасын пайдаланудың нысаналылығы расталды. "Халал" және "Органик" стандарттарын тексеру үшін өнімдердің "цифрлық төлқұжаттарының" әлеуеті көрсетілген, бұл елдің экспорттық позицияларын нығайту үшін маңызды. Net-Zero стратегиясының бөлігі ретінде көміртегі ізін дәл мониторингтеуге арналған IoT шешімдерімен блокчейн синергиясын зерттеу ұсынылды. Қостанай облысында транзакциялық шығындарды төмендету құралы ретінде астық қолхаттарын цифрлау мүмкіндігі қарастырылды.** ***Қорытындылар*** **— бұл жоба гибридті блокчейн-модельдерді қолдану ақпараттық асимметрияны тиімді азайтатынын және агробизнестегі деструктивті делдалдық буындарды жоятынын дәлелдейді. Авторлар ұлттық аграрлық блокчейн экожүйесін маңызды инфрақұрылымдық негіз ретінде орналастыру қажеттілігін теориялық тұрғыдан дәлелдеді. Бұл цифрлық шешім жер ресурстарына меншік құқығын тіркеу кезінде мінсіз заң тазалығына кепілдік береді және бюджеттік субсидияларды бөлу процесін толық автоматтандырады. Институционалдық тәуекелдерді бейтараптандыру контекстінде криптографиялық хаттамалардың мүмкіндіктері мен перспективаларының кең ауқымы көрсетілді, бұл қазақстандық аграрлық сектордың халықаралық деңгейде ұзақ мерзімді инвестициялық тартымдылығын айтарлықтай арттырады.**

Аннотация. ***Цель*** **– выявление системных барьеров цифровой трансформации и обоснование путей их преодоления через децентрализованные системы управления данными в растениеводстве и животноводстве.** ***Методы*** **– контент-анализ мировых практик за 2023-2025 гг., структурирована информация из государственных программ и пилотных проектов по токенизации активов и цифровой прослеживаемости продукции в республике для понимания тенденций и систематизации зарубежного и отечественного опыта.** ***Результаты*** **– проведена комплексная оценка интеграции технологии блокчейн в агропромышленный комплекс Республики Казахстан, определены основные механизмы внедрения распределенных реестров,**

включая автоматизацию агрострахования через метеорологические оракулы и смарт-контракты. Подтверждена целесообразность использования архитектуры Private Blockchain для соблюдения баланса между прозрачностью аудита и защитой коммерческой тайны агрохолдингов. Показан потенциал «цифровых паспортов» продуктов для верификации стандартов «Халал» и «Органик», что критично для укрепления экспортных позиций страны. Представлено исследование синергии блокчейна с IoT-решениями для точного мониторинга углеродного следа в рамках стратегии Net-Zero. Рассмотрена возможность оцифровки зерновых расписок в Костанайской области как инструмента снижения транзакционных издержек. *Выводы* — данный проект доказывает, что применение гибридных блокчейн-моделей эффективно минимизирует информационную асимметрию и устраняет деструктивные посреднические звенья в агробизнесе. Авторами теоретически аргументирована необходимость развертывания национальной аграрной блокчейн-экосистемы в качестве важного инфраструктурного базиса. Данное цифровое решение гарантирует безупречную юридическую чистоту при регистрации прав собственности на земельные ресурсы и полностью автоматизирует процесс распределения бюджетных субсидий. Продемонстрирован широкий спектр возможностей и перспектив криптографических протоколов в контексте нейтрализации институциональных рисков, что существенно повышает долгосрочную инвестиционную привлекательность казахстанского аграрного сектора на международном уровне.

Keywords: agro-industrial complex, blockchain technology, digital transformation, product traceability, transaction costs, subsidy automation, food security.

Түйінді сөздер: агроөнеркәсіптік кешен, блокчейн технологиясы, цифрлық түрлендіру, өнімнің қадағалануы, транзакциялық шығындар, субсидиялауды автоматтандыру, азық-түлік қауіпсіздігі.

Ключевые слова: агропромышленный комплекс, технология блокчейн, цифровая трансформация, прослеживаемость продукции, транзакционные издержки, автоматизация субсидирования, продовольственная безопасность.

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Introduction

Blockchain technologies offer Kazakhstan's agriculture unique avenues to lower operational costs, accelerate transactions, and eliminate redundant intermediaries. Amid urgent modernization, they provide a new management paradigm anchored in absolute trust, immutability, and end-to-end traceability. This integration remains crucial for achieving carbon neutrality and sustaining food supply chains.

Deploying distributed ledgers represents a critical priority for Kazakhstan’s agrifood industry to mitigate systemic inefficiencies. However, executing this digital strategy successfully requires identifying the key drivers shaping blockchain integration within the local agro-industrial complex. A comprehensive analysis of both technological barriers and catalysts remains essential for establishing a highly resilient, data-driven, and "smart" agricultural framework nationwide.

Global data show agriculture remains the vital livelihood for a major population segment, including in Kazakhstan. The domestic agro-industrial complex suffers because farmers, lacking advanced technical and business skills, cannot capture adequate profits, while extensive intermediaries absorb key financial margins. This excessive intervention and structural opacity deprive producers of fair income, as the missing direct link between creators and consumers fosters systemic inefficiencies and severe corruption risks.

Beyond logistics, Kazakhstan’s agricultural insurance system remains critically inefficient and overly bureaucratized for farmers seeking payouts. Integrating stakeholders via a publicly verifiable blockchain platform addresses this, while decentralized ledgers drastically lower transaction costs for financing environmental and insurance-related projects.

Implementing «programmable blockchain» through smart contracts is increasingly vital for Kazakhstan. These self-executing, decentralized codes prevent contractual falsification. Deploying such technologies across the critical infrastructure of the agro-industrial complex guarantees operational reliability and robust protection against unauthorized data access.

Within Kazakhstan's agricultural sector, three pivotal scenarios emerge: Traceability ensures origin and quality control, establishing supply chain transparency to mitigate counterfeit products; Automated insurance provides instantaneous payouts upon verified climatic risks; optimized logistics foster transparent participant interaction. Concurrently, blockchain

architectures facilitate Net-Zero strategy execution through rigorous resource accounting.

Implementing solutions like the AgriOn Block architecture ensures asset transparency and independent value-added chain audits. This minimizes consumer information uncertainty while securing property rights via beneficial owner registers, confirming blockchain-driven digital transformation as Kazakhstan's definitive path to a competitive agricultural sector.

Literature review

The academic discourse surrounding the digital transformation of agricultural value chains has evolved from purely technical considerations toward a comprehensive institutional analysis of decentralization. Current research emphasizes that sustainable development in the agrarian sector requires innovative principles that address the informational gaps between producers and end consumers. Saha A., Raut R., Yadav V. et al. [1] argue that the integration of blockchain technology is a fundamental prerequisite for achieving net-zero strategies, as it provides a transparent framework for monitoring carbon footprints across fragmented supply chains. This shift in management paradigms is further supported by the need to mitigate accumulated environmental and economic risks that threaten global food security.

The conceptual framework for blockchain-based traceability has been significantly advanced by the work of Akella G., Wibowo S., Grandhi S. et al. [2], who demonstrated that practical implementations of distributed ledgers can effectively eliminate the opacity inherent in traditional agrifood systems. Their research highlights how cryptographic protocols replace centralized trust with algorithmic verification, thereby reducing the "human factor" in quality control processes. Complementing this perspective, Patel H., Shrimali B. [3] explores the psychological and economic dimensions of transparency, identifying a direct correlation between blockchain-enabled data availability and the reduction of consumer uncertainty regarding product provenance and ethical standards.

The rise of decentralized autonomous systems in agriculture is not without its structural complexities. Chung Y., Adriaens P. [4] provide an extensive synthesis of how blockchain disrupts traditional power dynamics within the food industry by empowering primary producers through direct peer-to-peer interactions. This democratization of the supply chain is particularly critical in emerging economies, where market fragmentation often leads to the marginalization of small-scale farmers. Furthermore, the technical feasibility of these systems is grounded in the work of Zheng C., Peng X., Wang Z. et al. [5], who developed integrated models combining blockchain with Electronic Product Code Information Services (EPCIS) standards to ensure seamless data interoperability across diverse logistical nodes.

Institutional aspects of asset management in the digital age are addressed by Vignesh B., Chandrakumar M., Divya K. et al. [6], whose research focuses on the creation of decentralized registers for beneficial ownership. Such mechanisms are vital for ensuring the legal integrity of land rights and the equitable distribution of agricultural subsidies, which are often subject to corruption in centralized regimes. These findings resonate with the broader economic theories of transactional efficiency, where the reduction of intermediary rent-seeking becomes the primary driver of sectoral growth.

The integration of meteorological oracles and smart contracts into agricultural insurance represents another critical frontier in the literature. As noted by industry analysts and academic observers (Yadav N., Luthra S., Garg D. et al.; Hina M., Islam N., Luo X.) [7, 8], the automation of indemnity payments based on verifiable climatic data eliminates bureaucratic delays and enhances the financial resilience of agroholdings against volatile environmental conditions. In conclusion, the current body of literature suggests that the transition to a blockchain-based ecosystem in Kazakhstan’s agro-industrial complex (AIC) is not merely an option but a strategic necessity for maintaining global competitiveness and ensuring the long-term sustainability of the national food system.

Materials and methods

The methodological framework of this research is predicated on a multidimensional systemic approach, which is essential for evaluating the complex socio-economic and technological interactions inherent in the digital transformation of the agro-industrial complex. Given that the integration of blockchain technology is viewed as an institutional shift rather than a mere technical upgrade, the study employs a synthesis of descriptive, comparative, and analytical methods. The empirical basis of the research involves a comprehensive review of diverse datasets, including strategic government programs, legislative acts of the Republic of Kazakhstan, and international pilot project results documented in specialized scientific databases and global economic reports for the period of 2018–2025.

To ensure the validity of the findings, a systematic content analysis of both domestic and foreign academic literature was conducted, focusing on the intersection of distributed ledger technologies (DLT) and agricultural

productivity. The study utilizes a deductive reasoning approach to translate general principles of cryptographic immutability into specific agricultural scenarios, such as product traceability and automated subsidy distribution. Furthermore, the functional-structural method was applied to identify critical bottlenecks in the current logistical and financial nodes of the sector. The analytical part of the work is supplemented by a comparative evaluation of hybrid and private blockchain architectures to determine the most viable model for the Kazakhstani market. This combined methodology allows for a holistic assessment of the technological readiness of the industry and provides a robust foundation for formulating a strategic roadmap for the creation of a national agrarian blockchain ecosystem.

Results

This section examines the systemic challenges encountered by agricultural producers in Kazakhstan and justifies the potential of blockchain technology as a strategic instrument for their mitigation. Despite the availability of extensive land resources and consistent state support, the efficiency of domestic farming remains constrained by a set of critical factors:

Information asymmetry and the dominance of intermediaries: in the prevailing supply chain - spanning "farm - elevator -distributor -retailer"- the product price escalates manifold. The primary producer captures only a fractional share of the final value, while the bulk of the margin is accumulated by intermediaries. The absence of unified digital platforms leads to significant distortion of data regarding actual market price equilibrium.

Deficits in traceability: the processes related to crop cultivation, veterinary control (in livestock production), and logistics are frequently documented in a fragmented manner. This structural fragmentation undermines the credibility of Kazakhstani export brands, particularly those marketed under "Organic" or "Halal" certifications, as the end consumer lacks the means for instantaneous verification of product provenance.

Bureaucratization of agricultural insurance and subsidization: securing compensation for droughts or other climatic risks in the Republic of Kazakhstan remains an arduous process. Prolonged application review periods and the necessity of aggregating extensive physical documentation undermine the financial resilience of farming enterprises.

Data falsification risks: manual record-keeping systems permit the manipulation of data regarding product quality metrics or harvested volumes, which leads to the destabilization of the domestic market and a degradation in the safety standards of food products.

The application of distributed ledgers offers the following horizons for the Kazakhstani agro-industrial complex:

Transparency of value chains: blockchain records every transaction (shipment, quality appraisal, payment) in an immutable format. All market participants gain access to reliable, real-time information regarding product flows.

Equitable pricing mechanisms: the elimination of redundant intermediary nodes enables farmers to engage directly with retailers or export counterparties, ensuring marginality transparency at every operational stage.

Automation via smart contracts: the deployment of self-executing code facilitates the automation of insurance premiums and state subsidy disbursements. Upon the verification of an insured event (for instance, via satellite monitoring data), funds are transferred to the farmer's digital wallet automatically, bypassing bureaucratic delays.

Biosecurity assurance: in the livestock sub-sector, blockchain technology facilitates the rigorous verification of veterinary certifications and comprehensive animal movement histories, which is of critical importance for international export control and compliance with sanitary standards. Table 1 below provides a detailed content analysis regarding the implementation of blockchain and related digital technologies within the agricultural sector (both crop and livestock production) of the Republic of Kazakhstan.

Table 1 – Content analysis of blockchain and digital technology implementation in the agricultural sector (crop and livestock production) of the Republic of Kazakhstan

Sector	Project / Initiative	Brief Description	Status / Application in RK	Benefits / Objectives
Crop Production	Grain tokenization on blockchain (Kostanay region)	Transformation of physical grain into digital tokens for trading, settlements, and collateralized lending	Pilot project; scheduled launch in September 2025	Reduction in financing costs; fraud prevention; introduction of new market financial instruments

Crop Production	General Agrarian Digitalization Project	Implementation of integrated IT solutions, including unified digital management platforms	Active implementtation stage (multiple concurrent systems)	Increase in total factor productivity; optimization of administrative management
Agriculture / Blockchain Theory	Theoretical research on blockchain application	Academic assessment of DLT capabilities for supply chain tracking and trade operations	Scientific developments and policy recommendations	Supply chain transparency; guaranteed quality and provenance verification
Livestock Breeding	Electronic livestock traceability (QR / digital system)	New Information System for Identification of Agricultural Animals (ISIAA) module utilizing QR codes for end-to-end livestock tracking	Regional pilots (Almaty, Pavlodar, and Zhetysu regions)	Enhanced regulatory control; prevention of illegal slaughtering; biosecurity assurance
Livestock Breeding	Comprehensive livestock product tracing	"Digital traceability" from birth to the final point of sale	Included in the digitalization roadmap; government support	Transparency of value-added chains; strengthening of quality control mechanisms
Livestock Breeding / Digital Tech	Online services and Smart-Farms	Veterinary services and livestock monitoring via integrated digital ecosystems	Current realization (provision of online services for farmers)	Improved accessibility; automation of operational management
Livestock Breeding / RFID & Tags	RFID tagging for 90% of livestock by 2028	Digital tracking of individual animals through radio-frequency identification	Planned for mass-scale nationwide deployment	Improved real-time monitoring; integration with health and vaccination data
Experimental / Private Project	Blockchain-based NFT system for livestock accounting	Innovative project integrating blockchain, mobile gaming, and NFT for livestock records	Development stage / private initiative	Stimulating retail investment; transparency of beneficial ownership
International Piloting	Climate Smart Beef with blockchain integration	Sustainable livestock pilot utilizing blockchain-based validation for climate compliance	International agreement and partnership stage	Demonstration of sustainable practices; strengthening of export positions
Note: compiled by the authors				

The provided table conducts a comprehensive content analysis of the implementation of blockchain technologies and integrated digital solutions within the crop and livestock production sectors of the Republic of Kazakhstan. This analysis is predicated on a rigorous examination of open-source data, including strategic state programs, official news reports, academic publications, and the outcomes of diverse pilot initiatives.

The findings indicate that within the Republic of Kazakhstan, blockchain is primarily conceptualized as a strategic instrument for enhancing institutional transparency, product traceability, and systemic trust within the agro-industrial complex. In the crop production subsector, the fundamental focus is directed toward the digital accounting of grain products, specifically through asset tokenization. In this model, physical agricultural reserves are immutably recorded in a digital ledger, which facilitates the streamlining of trade operations, mitigates fraud-related risks, and broadens farmers' access to sophisticated financial instruments.

In the livestock sector, blockchain integration manifests predominantly through comprehensive digital traceability systems. The deployment of electronic identifiers, QR-codes, and centralized information databases ensures precise livestock accounting at every operational stage – from birth to final market realization. Although certain applications utilize related digital technologies rather than pure blockchain architectures, these systems essentially adhere to the core principles of distributed ledgers: data immutability, transparency, and decentralized oversight. Consequently, the data suggests that the digitalization of Kazakhstan's agrarian sector is a phased process, driven by pilot projects and state-led initiatives aimed at the fundamental modernization of the national agricultural economy.

Table 2 delineates the fundamental functional capacities of blockchain platforms and their practical significance in mitigating systemic agricultural challenges. Each analytical category unveils a distinct trajectory for blockchain application within the agro-industrial complex, encompassing both production-oriented and administrative-managerial processes.

Table 2 – Content analysis of factors determining the digitalization of the agro-industrial complex based on blockchain technologies

Analysis category	Key Strategic Aspects (Challenges & Solutions)
Traceability	Implementation of end-to-end monitoring systems from "farm-to-fork"; cryptographic verification of organic product provenance and quality standards.
Smart contracts	Automation of parametric insurance payouts; substantial reduction in transaction costs; systematic elimination of inefficient intermediary layers.
Environmental sustainability	High-precision monitoring of the carbon footprint; facilitating the achievement of Net-Zero objectives within grain supply chains.
Transparency	Mitigation of information uncertainty for the end consumer; combatting "greenwashing" through immutable data verification.
Data security	Enhancing the resilience of the AIC's critical infrastructure against unauthorized access, cyber threats, and data manipulation.
Asset management	Development of decentralized digital registries for land and machinery ownership rights to catalyze foreign and domestic investment.
Note: compiled by the authors	

In essence, blockchain in the agricultural sector represents more than a mere database; it functions as an integrative mechanism that consolidates fragmented segments of agribusiness into a unified, equitable ecosystem. Considering the issue of traceability, domestic exporters currently face significant hurdles in providing verifiable evidence that their grain is "environmentally clean" or that livestock products adhere to "Halal" standards. Blockchain addresses this through end-to-end monitoring, where every record concerning irrigation or veterinary intervention is cryptographically confirmed and immutable. This is intrinsically linked to transparency, as the ability of the consumer to access the full product history effectively neutralizes the "informational uncertainty" highlighted in recent research. Consequently, the mere application of aesthetic labeling is rendered insufficient, as the mitigation of "greenwashing" (unfounded environmental claims) becomes automated through data verification by algorithms rather than subjective human oversight.

From a financial perspective, the architecture relies on smart contracts - self-executing agreements that autonomously trigger disbursements upon the fulfillment of predefined criteria. In the insurance sub-sector, for instance, should satellite monitoring verify a drought event, the producer is relieved from the necessity of navigating bureaucratic procedures or providing physical documentation of losses. The system autonomously identifies the satisfaction of contractual conditions and facilitates the transfer of funds, thereby bypassing administrative hurdles and rent-seeking intermediaries. This approach radically diminishes transaction costs. Furthermore, such a framework is vital for data security; since the agro-industrial complex constitutes critical infrastructure, protecting information regarding grain reserves or the genetic integrity of breeding stock from unauthorized manipulation is a matter of national strategic security.

Another critically significant domain is asset management. In the socio-economic landscape of Kazakhstan, disputes frequently arise concerning land plots or the utilization of agricultural machinery. The creation of digital registries for ownership rights on a blockchain architecture renders the tenure system tran-sparent and intelligible for potential financiers. When an investor encounters a legally pristine asset history within a distributed ledger, the propensity for capital commitment increases substantially (Gilmour P., Pandey D., Goldbarsht D.) [9].

Ultimately, these mechanisms converge to enhance environmental sustainability. In the current global climate of heightened sensitivity toward the carbon footprint, securing premium prices for grain exports necessitates verifiable evidence of minimized CO2 emissions during the production cycle. Blockchain technology facilitates high-precision resource accounting, thereby enabling largescale agricultural holdings to align with Net-Zero strategies, which fundamentally bolsters the global competitiveness of domestic products.

Consequently, each analytical component of the results represents a strategic transition from chaotic and high-risk traditional farming to a high-technology agribusiness model, where institutional trust is predicated not upon the subjective reliability of an intermediary, but upon mathematical code that is inherently resistant to manipulation.

In recent years, the trajectory of academic inquiry has pivoted toward the synergy between blockchain and concurrent technologies such as the Internet of Things (IoT), machine learning, and wireless sensor networks. In the specific context of Kazakhstan, such integration is critically important for the sophisticated design of pasture monitoring systems, the automation of precision irrigation, and the comprehensive digital accounting of land resources.

Research conducted by Caro M., Ali M., Vecchio M. et al. [10], utilizing the AgriBlockIoT platform as a case study, demonstrates that the strategic selection between public (Ethereum) and private (Hyperledger) blockchain architectures directly impacts network latency and the consumption of computational resources. Within the context of Kazakhstan's infrastructure, which is characterized by vast geographical distances and a high degree of node distribution, the methodology must rigorously account for hardware constraints and the throughput capacity of communication channels.

The framework proposed by Leng K., Bi Y., Jing L. et al. [11] is particularly relevant for safeguarding the commercial confidentiality of the Republic of Kazakhstan's large-scale agricultural holdings. This architecture facilitates a strategic partition between public-facing information regarding product quality for consumers and private enterprise data (such as logistical expenditures and production costs). Simultaneously, it enables automated resource discovery and the self-adaptive matching of supply and demand within the market ecosystem.

The automation of data recording through integrated sensors, as opposed to manual entry, is considered the primary methodological safeguard against corruption and human error. However, as noted by researchers, a fundamental element of this methodology must be the deployment of smart contracts equipped with warning protocols. These algorithmic triggers automatically signal deviations in storage conditions, such as temperature fluctuations during the transportation of products along the entire "farm-to-fork" value chain.

The experience of the AgriLedger program in developing economies demonstrates that blockchain technology facilitates the identification of unscrupulous intermediaries who exploit small-scale farming operations. For Kazakhstan, this provides a solid methodological foundation for the establishment of "digital co-operatives," where smart contracts guarantee an equitable distribution of profits among all stakeholders within the value chain.

Furthermore, the implementation of blockchain in aquaculture, exemplified by the platform developed by Hang L., Ullah I., Kim D-H. [12], confirms the high efficacy of smart contracts in ensuring data integrity. Analogous algorithms within the AgriOnBlock methodology for the Republic of Kazakhstan are designed to automate veterinary control processes and provide robust verification for "Net-Zero" environmental standards.

Consequently, the proposed methodology is predicated on the creation of a trusted, self-organizing ecosystem (Duan J, Zhang C, Gong Y. et al.) [13]. It integrates real-time traceability, automated insurance disbursements, and the protection of the agrarian sector's intellectual capital - approaches validated by the results of a comprehensive content analysis of leading global practices spanning the period from 2023 to 2025.

Based on a critical analysis of contemporary research outcomes, this study posits the hypothesis that a hybrid blockchain model integrated with data oracles represents (Patel N.S., Bhattacharya P., Patel S.B. et al.) [14] the most adaptive framework for the agro-industrial complex of Kazakhstan. Diverging from strictly centralized systems, the proposed concept is predicated on the theoretical inference regarding the necessity of "algorithmic trust" wherein the fulfillment of obligations- such as subsidy disbursements and quality certifications - is rendered independent of subjective human factors.

We contend that the implementation of smart contracts, as delineated in the seminal works of Patel and Shrimali, will facilitate the mitigation of excessive intermediation within the specific economic landscape of the Republic of Kazakhstan. The theoretical model envisages the creation of an environment in which the smart contract functions as a digital guarantor: a transaction is finalized automatically only upon the synchronization of data from the primary producer and the verification from the logistical node, both of which are immutably recorded within the distributed ledger.

The analysis of technical findings by various authors allows us to propose the utilization of high-level programming languages, such as Solidity, to encode the logic of agricultural subsidies within the Republic of Kazakhstan. The

theoretical potential of this approach lies in its "Turing-Completeness," which permits the description of complex agrotechnical scenarios - for instance, the automated distribution of fuel and lubricants or seed stock based on verified data concerning sown areas.

Drawing on testing results within Ganache and Remix, we conclude that a Private/Permissioned Blockchain architecture represents the most viable solution for Kazakhstan. This is necessitated by the requirement to maintain a strategic balance between data transparency for regulatory authorities and the preservation of commercial confidentiality for private agricultural holdings, a position reinforced by Kaijun's "dual-chain architecture" theory (Patel H., Shrimali B.) [15].

Analyzing the conclusions of Chung and Adriance, we advocate for the implementation of an insurance model where smart contracts are integrated with meteorological oracles (satellite remote sensing data). The theoretical hypothesis posits that upon the verification of drought conditions in a specific region of the Republic of Kazakhstan, the system should trigger disbursements without the necessity for physical documentation. This mechanism would significantly diminish transactional overheads and enhance the financial viability of small-scale farming enterprises.

Based on the content analysis of the findings presented by Vignesh B., Chandrakumar M., Divya K. et al. [6] and Hina M., Islam N., Luo X. [8], we propose a "digital passport" model for commodity batches. Within the economic landscape of Kazakhstan, this framework is designed to address the persistent challenges of export product verification. The hypothesis posits that the immutability of data concerning the "farm-to-fork" trajectory of grain or livestock products effectively neutralizes the issue of "greenwashing" and substantially enhances the premium value of the Kazakhstani brand in international markets.

A pivotal outcome of this analysis is the strategic proposal for the implementation of decentralized registries for land ownership rights. Theoretically, such an architecture precludes the possibility of hostile takeovers and the unauthorized manipulation of cadastral data. Furthermore, drawing on the framework developed by Yadav N., Luthra S., Garg D. et al. [7], we advocate for the utilization of blockchain technology to facilitate the precise accounting of the carbon footprint associated with Kazakhstani wheat. This would enable domestic agricultural producers to integrate seamlessly into global carbon credit trading systems, thereby generating a sophisticated new revenue stream.

In conclusion, the synthesis of global research outcomes allows us to assert that blockchain technologies in Kazakhstan should be deployed not as an auxiliary superstructure, but as the foundational layer of critical national infrastructure. The proposed adaptive model is oriented toward the establishment of a self-organizing ecosystem, wherein technological transparency emerges as the primary determinant of sustainable development and the export competitiveness of the agro-industrial complex.

Discussions

Analytical results unequivocally confirm that blockchain technology represents a fundamental institutional pillar required to overcome the systemic crisis of trust and disproportionate intermediary influence within Kazakhstan's agro-industrial complex. Adapting decentralized architectures must rigorously account for the country's vast geographical distribution and fragmented small-scale farming enterprises.

Unlike international frameworks focusing primarily on combating corrupt middlemen, algorithmic trust in Kazakhstan centers on integration with state information systems. Theoretical modeling demonstrates that utilizing smart contracts facilitates a seamless environment where immutable product quality data automatically triggers access to preferential lending or export quotas, neutralizing administrative discretion.

Central to this discourse is end-to-end traceability, serving as a strategic instrument to safeguard the national agrarian brand in high-value foreign markets. For a nation aspiring to supply premium organic goods, a blockchain registry functions as a digital certificate of authenticity. Establishing a national traceability standard mitigates greenwashing risks, ensuring premium status by allowing consumers to verify product provenance, effectively resolving certification issues.

Furthermore, adapting smart contracts for agricultural insurance via independent satellite oracles ensures algorithmic justice and automatic fund disbursements during climate anomalies. This mechanism bypasses inefficient, stagnant digital archives. Ultimately, blockchain registries for beneficial ownership secure land rights, while carbon footprint metrics allow producers to monetize environmental efforts through tokenized carbon credits, establishing a globally competitive agrarian economy.

Conclusion

1. Integrating a decentralized architecture like AgriOnBlock into Kazakhstan's agricultural

sector represents a strategic imperative. This framework offers a comprehensive solution to systemic barriers by fostering financial transparency and eliminating the information asymmetry that traditionally undermines trust among market participants.

2. In conclusion, cryptographic protection and public verification ensure fiduciary accountability, driving efficiency within Kazakhstan's state-led agrarian framework. Transitioning to a smart-contract-based ecosystem places agricultural processes into an autonomous regime, where objective, immutable code replaces administrative discretion.

3. In conclusion, the proposed theoretical prototype for Kazakhstan eliminates data falsification risks and financial losses. By establishing a transparent digital infrastructure, this system effectively safeguards farmers against climate hazards, ensuring automated, immediate compensation while bypassing traditional bureaucratic delays.

4. Ultimately, this study establishes a foundation for future research regarding blockchain access control policies. Subsequent inquiries must focus on refining data rights to balance commercial confidentiality for private agro-holdings with the regulatory transparency required for comprehensive state audits.

5. Ultimately, evolving this digital paradigm toward specialized tokens and decentralized registries will catalyze a high-tech, carbon-neutral agricultural economy. Transparent subsidies and indisputable product quality will secure Kazakhstan's global food market leadership through guaranteed "farm-to-fork" traceability.

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