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Traceability of Honey Supply Chains in the Russian Federation: Data Architectures, Adoption Barriers, and an Industry Maturity Model

Igor Zakharian
IP Zakharyan
Moscow, Russia

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Abstract

This study examines how robust traceability can be established across honey and apiculture product supply chains within the Russian Federation. The methodological core rests on the analysis of contemporary data architectures that integrate blockchain (BC), the Internet of Things (IoT), and artificial intelligence (AI) as a toolset for lifecycle event capture, automated collection of primary data, and intelligent validation of record credibility. A comparative review of the regulatory regimes of the Russian Federation, the European Union, and the United States is conducted in order to identify divergences in batch identification requirements, record granularity, control mechanisms, and the allocation of responsibility among chain participants. Particular attention is given to institutional and technological constraints affecting the roll-out of digital labeling within the segment of household subsistence farms (LPH), which accounts for a substantial share of domestic production while simultaneously exhibiting limited capacity for digitalization, heterogeneous bookkeeping practices, and elevated transaction costs associated with migration to standardized registration procedures. A five-level industry maturity model is proposed to systematize the transition trajectory from fragmented accounting and dispersed control channels toward transparent, risk-oriented supply chains that ensure data reproducibility and strengthened product safety. The functional role of state information systems—FGIS "Mercury" and GIS MT "Chestny ZNAK"—is analyzed in relation to the formation of an integrated quality-control environment, the synchronization of data on origin, movement, and product status, and the enhancement of market observability for regulatory and supervisory purposes. The material targets specialists in agro-logistics, public regulators, and participants in the apiculture market.

Keywords: traceability; blockchain; Internet of Things (IoT); supply chains; honey adulteration; Russian Federation; GIS MT "Chestny ZNAK"; FGIS "Mercury"; maturity model; food security.

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1. Introduction

Globalization in the agri-food sector has driven the consolidation of multi-tier, spatially distributed value chains. Within these configurations, apiculture products stand out for a combination of high commercial attractiveness and methodological difficulty in the verifiable authentication of product integrity [1, 8]. Under such conditions, traceability—understood as the institutionally and technologically supported capacity to reconstruct origin, event history, and movement routes across the entire product life cycle—acquires the status of a central prerequisite for maintaining quality and consumer safety [2, 3]. Honey is among the food categories most vulnerable to adulteration at the global level. According to materials from the European Union's Joint Research Centre (JRC), up to 46% of examined imported honey samples exhibit indications consistent with probable intentional composition distortion, most commonly through the addition of low-cost sugar syrups [11, 18].

The state of the sector in the Russian Federation is characterized by a pronounced asymmetry in development parameters. External markets display notable positive dynamics: in 2024, the volume of overseas shipments increased by 40% and reached 5 thousand tons. At the same time, the domestic market experiences sustained pressure from structural factors, primarily associated with high decentralization and fragmentation of the production base. Up to 94% of honey is produced within the segment of household subsistence farms (LPH), which sharply complicates the unification of accounting procedures and reduces the reproducibility of data required for digital traceability.

The introduction of mandatory labeling within the "Chestny ZNAK" contour, along with its coupling to veterinary control mechanisms in FGIS "Mercury," is positioned as an instrument of structural transformation in sectoral oversight; nonetheless, practical implementation is accompanied by significant economic costs and technological constraints that impede scalable deployment in the small-commodity segment [4, 15, 16].

The purpose of this research is to analyze architectural approaches to building traceability systems, to compare international regulatory practices, and to develop a maturity model adaptable to Russian institutional conditions.

Scientific novelty is associated with the substantiation of a hybrid coupling scheme that links veterinary oversight mechanisms with commercial labeling, conceptualized as a lever for strengthening national interests in the domains of quality assurance and fair competition.

The author's hypothesis proceeds from the proposition that genuine market transparency, under conditions of small-producer predominance, becomes achievable primarily through the establishment of cooperative digital hubs that provide collective access to accounting infrastructure, standardize data, and reduce the transaction costs of digitalization.

Materials and Methods

The methodological design combines a systematic literature review with comparative analysis of regulatory frameworks. In preparing the material, publications indexed in Scopus and Web of Science from recent years were examined; the search strategy relied on descriptors such as "honey supply chain," "blockchain traceability," "food safety regulation," and "IoT agriculture." The analytical toolkit encompasses several complementary procedures.

The bibliometric component is directed toward identifying research trends associated with the diffusion of the Industry 4.0 paradigm into the agro-industrial complex, as well as toward documenting dominant technological and methodological approaches in the field of digital traceability [1]. Results indicate a prevalence of hybrid methodologies in which Ethereum and Hyperledger Fabric are treated as core platform foundations for constructing supply-chain event registration contours and for ensuring immutability of critically significant records [1, 2].

The comparative legal contour focuses on contrasting the requirements of EU Directive 2024/1438 ("Breakfast Directives"), provisions of the U.S. FSMA (Section 204), and the Russian regulatory corpus governing labeling and circulation of products [7, 10, 15, 16]. This approach makes it possible to expose discrepancies in the degree of data granularity, the mandatory fixation of key operations, and the institutional mechanisms of oversight and accountability applied to market participants.

The process-architectural block is implemented through modeling and the formation of a conceptual data scheme grounded in the use of decentralized identifiers (DIDs) and digital twins as means of persistently anchoring product identity in situations involving batch blending and redistribution of commodity flows [3, 4]. The proposed logic is oriented toward minimizing semantic loss of origin information during aggregation, packaging, and logistical transformations—an issue that becomes critical for authenticity verification and for evidentiary reconstruction of the event chain.

The empirical component is reinforced through expert interviews and analysis of sectoral reporting. Additionally, statistical arrays characterizing the dynamics of the Russian honey market are considered to align theoretical conclusions with measurable parameters of industry development and to strengthen the verifiability of the resulting generalizations [1, 8].

Results and Discussion

Traditional accounting contours, under contemporary conditions, no longer provide the level of transparency and evidentiary reproducibility required in globalized supply chains [2]. Their limitations become visible through the fragmentation of information arrays, the predominance of dispersed registries, and a high vulnerability to ex post adjustments. The practical consequence is predictable: causal links between operations are harder to establish, while confidence in product origin weakens—sometimes subtly, sometimes abruptly, but in ways that accumulate.

A modern traceability architecture is increasingly configured as a multi-layer digital system in which a distributed ledger built on blockchain serves as a “single source of truth,” ensuring immutability of critically significant records and synchronizing information among supply-chain participants [1, 2, 14]. This model relies on recording product lifecycle events as standardized transactions that bind batch identity to key operations—production, aggregation, transportation, storage, and sale—while reducing data manipulation risks via cryptographic verification and harmonized access rules [2, 3]. In other words, integrity is not treated as a moral expectation; it is engineered as a property of the system.

Table 1 specifies the architectural layers of a honey traceability system.

Table 1. Architectural layers of a honey traceability system (compiled by the author based on [2]).

Architecture layer	Technological components	Function in the honey supply chain
Physical (IoT)	RFID tags, QR codes, hive sensors, GPS trackers	Collection of data on apiary location, harvest time, and storage conditions
Network	5G, LPWAN, cloud computing	Continuous data transmission from apiaries to the registry
Registry (Blockchain)	Smart contracts, DLT (Distributed Ledger Technology)	Immutable recording of transactions, test results, and ownership rights
Validation (Oracles)	Laboratory interfaces, veterinary service APIs	Verification of physical data credibility prior to blockchain recording
Application	Mobile apps, regulator dashboards	Consumer access to product history; monitoring for public authorities

The dynamics of key sector parameters in the Russian Federation point to an institutional need to move away from predominantly ex post and fragmented control toward digital monitoring and traceability mechanisms capable of ensuring data comparability, risk governability, and verifiable confirmation of product origin. In such conditions, maintaining—and extending—an export trajectory becomes directly dependent on the existence of a digital contour that strengthens external-market trust by providing a reproducible evidentiary basis for quality assurance and the legitimacy of commodity flows [5, 7]. This is not merely about "showing documents." It is about producing a chain of records that remains interpretable and defensible when subjected to scrutiny.

Figure 1 provides an illustration of the dynamics of honey production and exports in the Russian Federation.

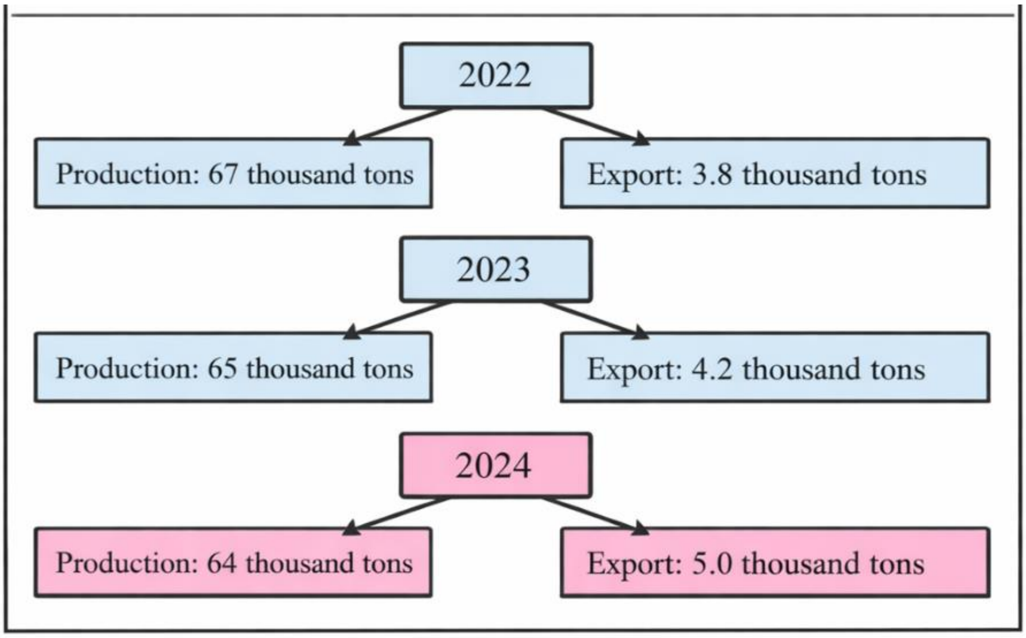

Fig. 1. Dynamics of honey production and exports in the Russian Federation (compiled by the author based on [5-7]).

A key innovative component of contemporary traceability systems is associated with the use of digital twins and decentralized identifiers (DIDs) [3]. In honey circulation, this approach becomes particularly consequential because it methodologically and technologically offsets the "identity loss" effect that emerges when raw material and batches from multiple suppliers are mixed at processing facilities. Within this logic, a digital twin functions as a formalized model of a batch with a fixed set of attributes—origin, quality parameters, control results, movement events, and transformation steps—while a DID provides persistent identification of that entity and continuity of links between source batches and derivative products, even under aggregation and redistribution of flows [3]. The practical outcome is a verifiable provenance chain that preserves evidentiary coherence in precisely those situations where conventional accounting methods lose the capacity for correct reconstruction.

International regulatory regimes governing honey traceability demonstrate pronounced heterogeneity in the depth of requirements, the structure of mandatory records, and control mechanisms, which collectively produces a fragmented global landscape. At the same time, an observable vector toward gradual harmonization is taking shape—implemented less through top-down standard unification than through tightening import requirements and strengthening evidentiary expectations for transparency of origin and composition from the perspective of importing countries [5, 7, 13]. In effect, convergence is often driven by border and market access logic, not by a single shared template.

Table 2 below presents the results of a comparison of traceability regulatory systems.

Table 2. Comparison of traceability regulatory systems (compiled by the author based on [5, 7, 13]).

Parameter	Russian Federation (Mercury + Chestny ZNAK)	EU (TRACES + RASFF)	United States (FSMA + FDA)
Primary objective	Verification of volumes and veterinary safety	Brand protection and consumer rights	Food safety and economically motivated adulteration (EMA)
Labeling modality	Data Matrix code (mandatory)	Text labeling + digital traceability	Batch accounting via KDE/CTE
Control method	Automated cross-checking of veterinary accompanying documents (VSD) and marking codes (KIZ)	Pollen analysis, NMR spectroscopy	Isotope analysis (SCIRA)
Timeline	Full control targeted for 2026–2029	In force; strengthening in 2026	In force; compliance window in 2024–2025

For implementing control in the Russian Federation, a distinctive coupling of two state systems is used; the interaction scheme is presented below in **Figure 2.**

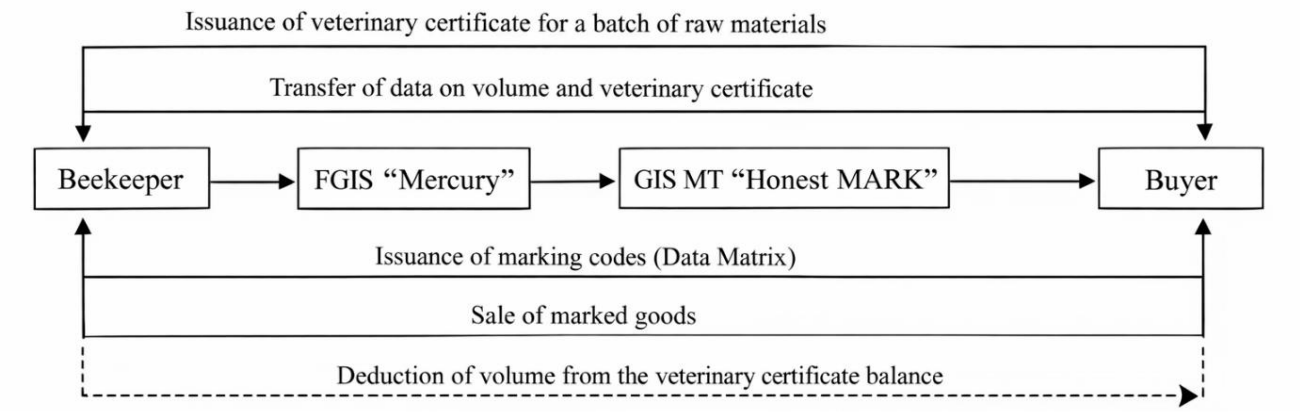

Fig. 2. Author’s model for integrating FGIS “Mercury” and GIS MT “Chestny ZNAK” (compiled by the author based on [5]).

In the context under consideration, traceability functions as a critically important instrument for demonstrating that products do not contain unacceptable residues of antibiotics and pesticides. The use of tetracyclines and chloramphenicol in the treatment of bee diseases creates risks associated with the development and dissemination of antibiotic resistance in consumers, with the risk profile shaped not only by the presence of residues per se, but also by the difficulty of proving their point of origin when records are incomplete or fragmented [9, 17]. An additional factor that amplifies the significance of traceability is the scale of adulteration. In domestic quality-control discourse, including assessments attributed to Roskachestvo, up to 80% of honey presented on retail shelves in 2024 is described as exhibiting indications of substitution or deviations from declared characteristics; the broader international analytical evidence likewise confirms the high incidence of suspicious samples within coordinated control actions and laboratory screening campaigns [11, 18]. A digital control contour, in this configuration, makes it possible to operationalize the response: detected non-compliant batches can be promptly reclassified into a circulation-restricted status, enabling the practical blocking of such batches in a mode close to real time—less as a declarative “ban,” more as a technically enforced exclusion from legitimate turnover.

Figure 3 presents a schematic of the cyber-physical architecture for honey quality control.

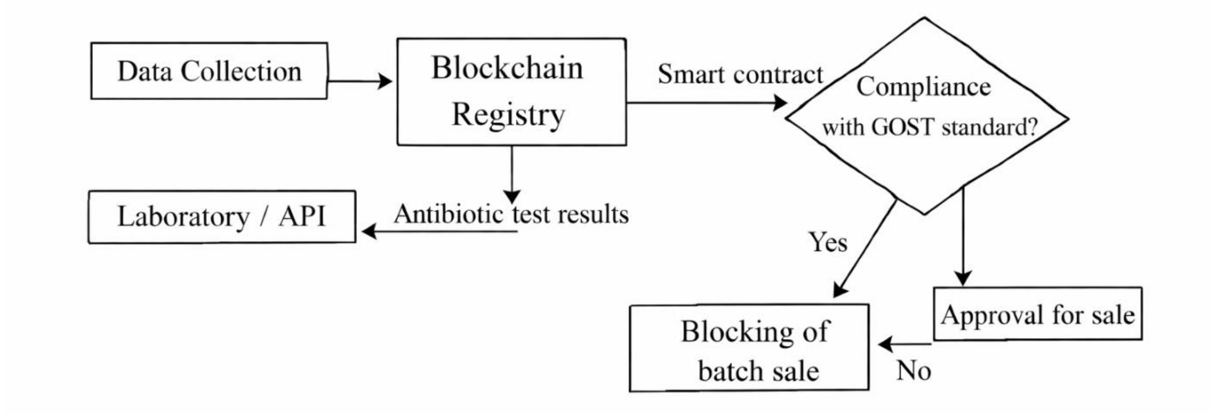

Fig. 3. Scheme of a cyber-physical architecture for honey quality control (compiled by the author based on [8, 9, 11]).

The introduction of labeling is reasonable to interpret as an institutional barrier for producers of glucose–fructose syrups that imitate natural honey through compositional substitution and marketing mimicry [7, 12, 18]. At the same time, apiculture increasingly takes on the character of a strategic pollination resource, since its contribution to the productivity of adjacent agricultural crops is commonly assessed as a 30–50% increase in yields. Within this framing, the protection of national interests implies not only the strengthening of supervisory and control contours, but also the reduction of regulation-driven costs for small producers. One practical route is the development of cooperative certification centers that concentrate quality-confirmation infrastructure and provide procedural support—particularly for the small-commodity segment, where standalone digitalization often becomes prohibitively expensive and organizationally burdensome [6, 15, 16, 19].

Based on the analysis, a five-level maturity model is proposed. It describes the sequential evolution of traceability from initial forms of recordkeeping toward a stable digital contour that ensures data comparability, verifiable provenance, and risk governability across the supply chain (see Table 3).

Table 3. Maturity model for honey supply chains (compiled by the author based on [5–7]).

Maturity level	Characterization	Technology stack	Status in the Russian Federation (2025)
L1: Ad hoc	Paper-based accounting; traceability absent.	Logbooks, invoices	30% of LPH
L2: Digital, siloed	Local automation at enterprises.	Excel, 1C without export to state GIS	40% of processors
L3: Integrated	Mandatory data transfer to state systems.	State GIS APIs, EDI / e-document flow	Target state for 2026
L4: Automated	“From the hive” monitoring in near real time.	IoT, blockchain, RFID	Pilot projects
L5: Cognitive	Predictive risk analytics via AI.	AI, digital twins, smart contracts	Outlook 2030+

Thus, the transition to digital honey traceability is not a narrow technological upgrade. It functions as a response to systemic constraints of traditional accounting, which—under conditions of globalized supply chains—fails to provide either sufficient transparency or evidentiary reproducibility, given persistent data fragmentation and susceptibility to post hoc modification [2, 5].

Conclusion

The results obtained confirm that traceability constitutes a critically important condition for ensuring food security, because it forms an evidentiary contour for provenance and for verifying product compliance within the supply chain. The transition to mandatory labeling in 2025–2026 is interpreted as a systemic measure capable of substantially reducing the share of adulterated products on the market while simultaneously strengthening the export position of the Russian Federation by increasing confidence in quality assurance and in the reproducibility of underlying data. The final conclusions underscore the fundamental importance of coupling physico-chemical analytical methods with decentralized data registries, since such an approach provides both laboratory verifiability of indicators and durable immutability of records concerning control results and batch movements. The stated research objectives have been achieved; the hypothesis regarding the necessity of systemic digital transformation is supported by the analysis.

References

1. Saidu, I., Shuhidan, S. M., Adamu, A. A. A., Raji, A., & Amin, S. (2025). Convergence of blockchain, IoT, and AI for enhanced traceability systems: A comprehensive review. IEEE Access, 13, 16838–16865. https://doi.org/10.1109/ACCESS.2025.3528035
2. Ellahi, M., Wood, D., & Bekhit, A. E.-D. A. (2023). Blockchain-based frameworks for food traceability: A systematic review. Foods, 12(16), 3026. https://doi.org/10.3390/foods12163026
3. Cordeiro, I. P., & Ferreira, J. C. (2025). Beyond traceability: Decentralised identity and digital twins for verifiable product identity in agri-food supply chains. Applied Sciences, 15(11), 6062. https://doi.org/10.3390/app15116062
4. Lai, M. B., Vergamini, D., & Brunori, G. (2025). Food supply chain: A framework for the governance of digital traceability. Foods, 14(12), 2032. https://doi.org/10.3390/foods14122032
5. Stricter traceability requirements are taking over the European honey market | CBI. Retrieved from: https://www.cbi.eu/news/stricter-traceability-requirements-are-taking-over-european-honey-market (date accessed: October 8, 2025).
6. Honey | European Commission. Retrieved from: https://agriculture.ec.europa.eu/farming/animal-products/honey_en(date accessed: December 5, 2025).
7. Directive (EU) 2024/1438 of the European Parliament and of the Council of 14 May 2024 amending Council Directives 2001/110/EC relating to honey, 2001/112/EC relating to fruit juices and certain similar products intended for human consumption, 2001/113/EC relating to fruit jams, jellies and marmalades and sweetened chestnut purée intended for human consumption, and 2001/114/EC relating to certain partly or wholly dehydrated preserved milk for human consumption | EUR-Lex. Retrieved from: https://eur-lex.europa.eu/eli/dir/2024/1438/oj/eng (date accessed: October 14, 2025).
8. Scoppola, M. (2022). Agriculture, food and global value chains: Issues, methods and challenges. Bio-Based and Applied Economics, 11(2), 91–92. https://doi.org/10.36253/bae-13517
9. Al-Waili, N., Salom, K., Al-Ghamdi, A., & Ansari, M. J. (2012). Antibiotic, pesticide, and microbial contaminants of honey: Human health hazards. The Scientific World Journal, 2012, Article 930849. https://doi.org/10.1100/2012/930849
10. FSMA Final Rule on Requirements for Additional Traceability Records for Certain Foods | FDA. Retrieved from: https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-requirements-additional-traceability-records-certain-foods (date accessed: December 16, 2025).
11. Official controls: Food fraud 2021–2022—Honey report (EU Coordinated Action). Retrieved from: https://food.ec.europa.eu/system/files/2023-03/official-controls_food-fraud_2021-2_honey_report_euca.pdf (date accessed: October 22, 2025).
12. Honey Risk Profile | FSA Research and Evidence. Retrieved from: https://science.food.gov.uk/article/121411-honey-risk-profile.pdf (date accessed: November 30, 2025).

13. Honey and Other Apiculture Export Lists | FDA. Retrieved from: https://www.fda.gov/food/food-export-lists/honey-and-other-apiculture-export-lists (date accessed: November 2, 2025).
14. FY21/22 Sample Collection and Analysis of Imported Honey for Economically Motivated Adulteration | FDA. Retrieved from: https://www.fda.gov/food/economically-motivated-adulteration-food-fraud/fy2122-sample-collection-and-analysis-imported-honey-economically-motivated-adulteration (date accessed: November 8, 2025).
15. Product labeling in 2026: Calendar and full list of product groups | MoySklad. Retrieved from: https://www.moysklad.ru/poleznoe/markirovka-tovarov/kalendar-markirovki/ (date accessed: November 15, 2025).
16. Honey labeling in 2025 | Online-Kassa. Retrieved from: https://online-kassa.ru/blog/markirovka-meda/ (date accessed: October 26, 2025).
17. Rodrigues, H., Leite, M., Oliveira, B., & Freitas, A. (2024). Antibiotics in honey: A comprehensive review on occurrence and analytical methodologies. Open Research Europe, 4, 125. https://doi.org/10.12688/openreseurope.17664.2
18. Ždiniaková, T., Lörchner, C., De Rudder, O., Dimitrova, T., Kaklamanos, G., Breidbach, A., Respaldiza, A., Vaz Silva, I. M., Paiano, V., Ulberth, F., & Maquet, A. (2023). EU coordinated action to deter certain fraudulent practices in the honey sector: Analytical testing results of imported honey (EUR 31461 EN; JRC130227). Publications Office of the European Union. Retrieved from: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130227/JRC130227_01.pdf (date accessed: December 20, 2025).
19. Apimondia. (2025). Apimondia 2025: Final program book. Retrieved from: https://apimondia2025.com/assets/docs/program/final-program-book.pdf?a=4567 (date accessed: October 3, 2025).