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Development Of A Web-Based Integrated Agricultural Information And Market Linkage System With Ai-Powered Assistance For Multi-Sector Farmers In Luuka District, Uganda

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Abstract

This study documented the development and evaluation of a web-based integrated agricultural information and market linkage system with artificial intelligence-powered assistance for multi-sector farmers in Luuka District, Uganda. Smallholder farmers in Luuka District faced chronic challenges in accessing timely and relevant agricultural information, identifying reliable markets for their produce, and receiving expert agronomic guidance all of which contributed to persistent post-harvest losses estimated at 30–40% of total production and suboptimal farm incomes. The study employed a Design Science Research (DSR) methodology, progressing through needs analysis, system design, prototype development, deployment, and evaluation phases. The system was developed using PHP, MySQL, JavaScript, and integrated an AI-powered chatbot using the OpenAI GPT API. System usability was evaluated using the System Usability Scale (SUS) with 45 farmer users and 10 agricultural extension officers. The developed system achieved a SUS score of 78.4 (classified as 'Good'), with particularly high scores for information accessibility (4.32/5) and market linkage functionality (4.18/5). The study concluded that the system significantly improved farmers' access to timely agricultural information and market opportunities, and recommended scaling the platform to additional districts through phased deployment and sustained government and development partner investment.

Keywords: Agricultural Information System, AI-Powered Chatbot, Market Linkage, Smallholder Farmers, Luuka District, Uganda, Web-Based System, Design Science Research

1.0 Background of the Study

Agriculture remained the cornerstone of Uganda's economy, employing approximately 69% of the working population and contributing 24% to the Gross Domestic Product (GDP) as of 2022 (Uganda Bureau of Statistics, 2022). The sector was dominated by smallholder farmers who cultivated parcels typically smaller than 2 hectares and operated largely within subsistence or semi-commercial frameworks(Frank et al., 2023). Despite the sector's economic centrality, smallholder agricultural productivity in Uganda remained significantly below its potential, constrained by a complex set of structural, informational, and market access challenges that persistently undermined farm income generation and household food security(Alex & Julius, 2024).

Information asymmetry was identified as one of the most pervasive and debilitating constraints facing Ugandan smallholder farmers. Research conducted by the International Food Policy Research Institute (IFPRI) demonstrated that farmers with timely access to weather information, pest and disease outbreak alerts, improved seed availability data, and post-harvest handling guidance achieved yields between 15% and 45% higher than their information-deprived counterparts (IFPRI, 2019). Conversely, the absence of reliable market information including current prices at local, regional, and national markets left farmers vulnerable to exploitation by intermediary traders who leveraged

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their information advantage to purchase farm produce at prices far below market value, capturing a disproportionate share of the value chain surplus(Julius & Kaazara, 2025).

Luuka District, located in the Busoga sub-region of eastern Uganda, exemplified these challenges. With an agricultural economy centred on maize, beans, cassava, groundnuts, and horticultural vegetables, Luuka's approximately 78,000 smallholder farm households depended on agriculture for both subsistence and income generation(Oromo et al., 2023). Yet the district's agricultural information infrastructure remained severely underdeveloped: extension officer ratios stood at approximately 1:1,500 farm households, compared to the recommended 1:500 ratio; mobile phone penetration, while growing, was concentrated among male household heads with limited access for women farmers; and internet connectivity remained intermittent, limiting the effectiveness of existing information platforms that assumed consistent data connectivity.

The emergence of web-based agricultural information systems and mobile-enabled market platforms had created new possibilities for bridging the information gap faced by smallholder farmers. Countries including Kenya (DigiFarm), Ethiopia (Digital Green), and India (e-Choupal) had demonstrated that technology-enabled agricultural information systems could dramatically improve farmer knowledge, decision-making quality, and market access. In Uganda, while platforms such as Farmbook and the National Agricultural Advisory Services (NAADS) digital extension system had made partial inroads, they had not been designed for the specific cropping systems, market dynamics, and connectivity constraints of districts like Luuka. There was therefore an urgent need to develop and evaluate a context-specific, integrated agricultural information and market linkage system that incorporated AI-powered assistance to supplement the limited formal extension capacity in the district.

2.0 Problem Statement

Smallholder farmers in Luuka District experienced chronic and compounding challenges in accessing the agricultural information and market linkages needed to improve their productivity and incomes(Julius & Nancy, 2026). A needs assessment conducted during the preliminary research phase revealed that 73% of surveyed farmers had never received agronomic advice from a formal extension officer during the previous growing season(Grace et al., 2023). Of those who had received advice, only 28% described it as timely and relevant to their immediate farming challenges. Post-harvest loss estimates from district agricultural records indicated losses of between 30% and 40% of total maize and vegetable production annually losses attributable primarily to inadequate post-harvest handling knowledge, lack of access to appropriate storage technologies, and inability to time market sales to coincide with price peaks(Kazaara & Julius, 2025).

Market information deficits compounded these challenges. Surveys conducted in Luuka markets found that the average price paid to farmers by first-level buyers was 35–55% below the prices prevailing at Kampala's wholesale markets, indicating a significant information-driven price differential that systematically disadvantaged producers. Farmers reported being unaware of market prices beyond their immediate local market, limiting their ability to negotiate favourable prices or identify alternative market channels(Ariyo, 2023). The absence of a coordinated

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platform linking Luuka farmers to buyers at district, regional, and national levels perpetuated this informational exclusion and curtailed farmers' market power.

Existing agricultural information systems available in Uganda were insufficient to address these challenges in Luuka's specific context. Most platforms required consistent internet connectivity not reliably available in rural Luuka; were developed for national audiences without adaptation to Luuka's specific crop calendar and market structure; lacked AI-powered interactive assistance that could provide personalized agronomic guidance; and did not integrate market linkage with information provision in a unified system. The development of a locally contextualized, integrated, AI-enabled system therefore represented an urgent and strategically important innovation for transforming agricultural information access in Luuka District.

3.0 Main Objective

The main objective of this study was to develop and evaluate a web-based integrated agricultural information and market linkage system with AI-powered assistance for multi-sector farmers in Luuka District, Uganda. The specific objectives were: (i) to identify the agricultural information and market linkage needs of farmers in Luuka District; (ii) to design and develop a web-based integrated agricultural information and market linkage system with AI-powered assistance; (iii) to evaluate the usability and functionality of the developed system among target users in Luuka District.

4.0 Literature Review

4.1 Theoretical Framework

The study was guided by three theoretical frameworks. The Technology Acceptance Model (TAM), originally proposed by Davis (1989) and subsequently extended by Venkatesh and Bala (2008), provided the evaluative lens for assessing farmer adoption and acceptance of the developed system. TAM posited that technology adoption was determined primarily by users' perceptions of a system's usefulness and ease of use, which collectively shaped attitudes toward technology adoption and actual usage behaviour. Applied to the agricultural technology context, TAM predicted that farmers would adopt the web-based system if they perceived it as improving their agricultural decision-making and income outcomes (perceived usefulness) without requiring disproportionate cognitive or technical effort (perceived ease of use). The model's emphasis on user perception made it particularly appropriate for evaluating systems intended for adoption by populations with limited formal technology experience.

Information Systems Design Theory (Walls et al., 1992) provided the methodological foundation for the system development process, emphasising that the design of information systems should be theoretically grounded, empirically validated, and explicitly oriented toward addressing well-defined practical problems. The theory prescribed a kernel theory (the theoretical rationale for the design), design principles (specific guidelines derived from the kernel theory), and meta-requirements (the class of problems the system addressed) — all of which were operationalised in the development of the Luuka Agricultural Information and Market Linkage System (LAIMLS).

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This framework ensured that system design decisions were anchored in both academic theory and empirical user needs assessment.

Diffusion of Innovations Theory (Rogers, 2003) offered insights into how the developed system might spread through Luuka's farming communities following initial deployment. Rogers identified five attributes that determined the rate of innovation adoption: relative advantage, compatibility with existing practices, complexity, trialability, and observability. Each of these attributes was explicitly considered in the system design process, with particular attention to ensuring that the system offered observable advantages over existing information access methods, was compatible with farmers' existing mobile phone and radio habits, and was triable at low risk and cost.

4.2 Agricultural Information Systems

Agricultural information systems (AIS) encompassed a broad range of technological and institutional mechanisms for collecting, storing, processing, and disseminating agricultural information to relevant stakeholders. Research on AIS deployments across sub-Saharan Africa documented significant positive impacts on farmer knowledge, decision-making, and productivity when systems were designed with appropriate attention to local context, user literacy levels, and connectivity constraints(Allan et al., 2023). A systematic review by Nakasone et al. (2014) found that agricultural information interventions in developing countries improved productivity by an average of 9.1%, with impacts concentrated in pest and disease management, input selection, and market price awareness categories.

Web-based AIS offered particular advantages over earlier-generation SMS or radio-based systems in terms of information richness, interactivity, multimedia content support, and integration capability. However, they also introduced new challenges related to internet access requirements, device compatibility, and digital literacy. Successful web-based AIS deployments in East Africa, including Kenya's iShamba and Tanzania's Ulimi wa Kisasa, demonstrated that these challenges could be mitigated through offline-capable design, local language interfaces, and community-based digital access points such as village internet kiosks.

4.3 AI-Powered Agricultural Assistance

The integration of artificial intelligence particularly natural language processing (NLP) and machine learning into agricultural advisory systems represented the frontier of agricultural information technology(Kazaara et al., 2024). AI-powered chatbots, expert systems, and predictive analytics tools had demonstrated capacity to provide personalized, contextualized agronomic guidance at scale, effectively extending the reach of formal extension services beyond the geographic and capacity limitations of human advisory systems. Research by Doshi-Velez et al. (2017) highlighted the importance of explain ability and trust in AI systems deployed for decision-making in high-stakes contexts such as agriculture, where farmer livelihoods depended on the quality and reliability of AI-generated recommendations(Audrey & Kazaara, 2025).

In Uganda, the application of AI in agricultural information systems remained nascent but had attracted growing interest from government agencies, development partners, and technology startups. The International Institute of Tropical Agriculture (IITA) had piloted AI-powered pest diagnosis tools for cassava disease detection using image

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recognition, while Makerere University's Department of Computer Science had developed machine learning models for crop yield prediction. The development of the LAIMLS sought to build on these foundational efforts by integrating AI-powered conversational assistance into a broader agricultural information and market linkage platform, with specific adaptation to Luuka District's farming context.

5.0 Methodology

5.1 Research Design

The study employed Design Science Research (DSR) methodology, as conceptualized by Hevner et al. (2004), which was oriented toward the development and evaluation of innovative IT artefacts designed to solve well-defined practical problems. The DSR methodology comprised six activities applied in the study: problem identification and motivation; definition of objectives for the solution; design and development of the artefact; demonstration; evaluation; and communication(Winny et al., 2023). This methodology was deemed particularly appropriate for the study because it provided a rigorous, theoretically grounded framework for IT artefact development that explicitly integrated both technical system development and user-centred evaluation.

5.2 System Requirements Analysis

System requirements were identified through a structured needs assessment involving 60 farmers, 15 extension officers, 5 agricultural traders, and 3 district agricultural officials selected through purposive and snowball sampling. Data collection methods included focus group discussions, key informant interviews, and a structured questionnaire. The needs assessment confirmed farmers' priority information needs as: current crop prices at local and regional markets; weather and climate advisory for seasonal planting decisions; pest and disease identification and management guidance; input supplier locations and prices; and post-harvest handling techniques. Market linkage needs included: buyer directories with contact information; produce aggregation opportunities; and transportation and storage facility locations.

5.3 System Architecture and Development

The LAIMLS was developed using a multi-tier web architecture comprising a presentation layer (HTML5, CSS3, JavaScript, Bootstrap 5), a business logic layer (PHP 8.0), and a data management layer (MySQL 8.0). The system was hosted on a cloud server (DigitalOcean Droplet, 4GB RAM, 2 CPUs) accessible via standard web browsers on desktop and mobile devices. The AI-powered chatbot component was implemented using the OpenAI GPT-3.5 Turbo API, with a customised system prompt trained on Luuka-specific agricultural data including local crop calendars, common pest and disease profiles, and district market structures. The chatbot was designed to support both English and simple Luganda queries, recognising the bilingual literacy environment of the target user population. A responsive mobile-first design was adopted to optimise system performance on smartphone devices, which were the primary internet access modality for Luuka's farming population.

5.4 System Evaluation

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System usability was evaluated using the System Usability Scale (SUS), a validated 10-item instrument that generated a composite usability score on a 0–100 scale, with scores above 70 classified as 'Good' and scores above 85 classified as 'Excellent'. The SUS was administered to 45 farmer users and 10 agricultural extension officers following a structured system demonstration and guided usage session. Functionality was assessed through a structured functionality checklist applied by the research team and confirmed against the system requirements specification. Qualitative evaluation data were collected through post-session interviews with a subsample of 15 farmers and 5 extension officers.

6.0 Results

6.1 System Functionality Assessment

Table 1: System Module Functionality Assessment Results

System Module	Features Developed	Features Functional	Functionality (%)	User Rating (Mean/5)
Agricultural Information Hub	12	12	100.0	4.32
Market Price Information	8	8	100.0	4.18
AI-Powered Chatbot	10	9	90.0	4.05
Buyer-Seller Linkage	7	7	100.0	4.22
Weather Advisory	6	5	83.3	3.87
Input Supplier Directory	5	5	100.0	4.11
Post-Harvest Guidelines	6	6	100.0	4.28

Source: Primary Data, 2025

Table 1 presents the results of the functionality assessment conducted for each of the seven core modules of the LAIMLS. Five modules the Agricultural Information Hub, Market Price Information, Buyer-Seller Linkage, Input Supplier Directory, and Post-Harvest Guidelines achieved 100% functionality against their specified requirements. The AI-Powered Chatbot module achieved 90% functionality, with one feature (multilingual voice input in Lusoga) remaining under development at the time of evaluation due to limited training data availability. The Weather Advisory module achieved 83.3% functionality, as one planned integration with Uganda Meteorological Authority's real-time weather API encountered technical delays. User satisfaction ratings were highest for the Agricultural Information Hub (M=4.32/5) and Post-Harvest Guidelines (M=4.28/5), reflecting the centrality of practical agronomic content to farmers' perceived system value.

6.2 System Usability Evaluation

Table 2: System Usability Scale (SUS) Results by User Category

User Category	N	Mean SUS Score	Std. Dev.	Min	Max	Classification

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Farmer Users	45	77.8	8.34	60.0	95.0	Good
Extension Officers	10	81.5	6.21	72.5	90.0	Good
Combined	55	78.4	8.12	60.0	95.0	Good

Source: Primary Data, 2025

Table 2 presents the SUS scores obtained from the system usability evaluation. The combined SUS score of 78.4 confirmed that the LAIMLS achieved a 'Good' usability rating, exceeding the minimum threshold of 70 required for acceptable usability. Extension officers recorded a slightly higher mean SUS score (81.5) compared to farmer users (77.8), reflecting their greater familiarity with technology and web-based platforms(Nelson et al., 2023). However, the farmer user SUS score of 77.8 was notably strong for a first-generation system evaluated with a predominantly rural, low digital-literacy user population, indicating that the mobile-first, simplified interface design had been effective in addressing usability barriers. Qualitative interview data identified navigation simplicity, local language content, and the AI chatbot's ability to provide personalised advice as the most valued system features. The most commonly cited usability improvement priorities were: faster page loading speed in low-bandwidth conditions, inclusion of offline functionality for areas without consistent internet coverage, and addition of audio content for users with limited reading literacy.

7.0 Conclusions

The study concluded that a web-based integrated agricultural information and market linkage system with AI-powered assistance could be successfully developed and deployed in a resource-constrained smallholder farming context such as Luuka District, Uganda. The LAIMLS achieved high functionality rates across its core modules and demonstrated acceptable usability among both farmer users and agricultural extension officers, supporting the conclusion that the system represented a viable technological solution to the agricultural information and market access deficits that had chronically undermined farm productivity and income in the district. The AI-powered chatbot, in particular, demonstrated significant potential as a scalable mechanism for extending personalized agronomic advisory services beyond the reach of formal extension systems.

The study also concluded that context-specific design including adaptation to local crop calendars, market structures, and language preferences was critical to achieving acceptable usability among rural farmer users. Generic agricultural information platforms that failed to incorporate local context had limited uptake among smallholder farmers whose information needs were highly location- and crop-specific. The design of the LAIMLS accordingly incorporated Luuka-specific agricultural data at every level of the system, from the AI chatbot's training corpus to the market price databases and input supplier directories.

8.0 Recommendations

Based on the findings, it was recommended that the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) explored the integration of the LAIMLS framework into its national digital agriculture strategy, with phased scaling to additional districts following further validation and refinement. The developers should prioritise the addition of

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offline functionality and progressive web application (PWA) capabilities to address connectivity barriers in low-bandwidth rural environments. The AI chatbot should be expanded to support additional local languages including Lusoga and Lunyankole, and voice-based query processing should be developed to accommodate users with limited reading literacy. Development partners including FAO, IFAD, and the World Bank should be engaged to provide grant funding for the hosting, maintenance, and rural digital access infrastructure required to sustain the platform. A structured impact evaluation should be conducted 18 months after full deployment to assess changes in farmer knowledge, market access, and income attributable to LAIMLS use.

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