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Bridging Extension Gaps through Digital Advisory Systems: Lessons from a Mobile Expert System for Rice Farmers in Nigeria

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ABSTRACT

Agricultural extension services remain unevenly distributed across rural Nigeria, limiting smallholder farmers' access to timely and context-specific agronomic knowledge. This study examines the role of mobile-based expert systems as a socio-technical intervention for strengthening agricultural extension in resource-constrained rural settings. Using a Design Science Research approach, we developed and evaluated *RiceAdvisor*, a mobile expert system designed to support rice disease diagnosis and management among smallholder farmers. System requirements were informed by survey data collected from 270 rice farmers across three agro-ecological zones in Nigeria, highlighting critical gaps in disease diagnosis, extension access, and decision support. The system integrates localized expert knowledge, rule-based reasoning, multilingual interaction, and offline functionality to accommodate rural infrastructural and literacy constraints. Usability evaluation with 50 farmers produced a System Usability Scale score of 76.5, indicating acceptable to good usability and perceived relevance. Findings suggest that mobile expert systems can enhance farmers' confidence, problem-solving capacity, and access to extension knowledge, particularly in contexts where conventional advisory services are limited. The study contributes to rural studies and agricultural extension services by demonstrating how digital advisory tools can be designed and embedded within rural knowledge systems to support sustainable agricultural practices in Nigeria.

Introduction

Nigeria is endowed with extensive arable land and diverse agro-ecological zones, which have significant potential for rice cultivation. Despite this, the country's average rice yield remains low, at approximately 2.0 to 2.5 tons per hectare, considerably below the global average of about 4 tons/ha and Asia's 6 tons per hectare (PwC, 2018; USDA, 2020). This low productivity is attributed to several factors, including limited mechanization, reliance on traditional farming methods, small landholdings, and inadequate pest and disease management (Ogunlela and Mukhtar, 2009). These challenges contribute to a substantial supply-demand gap; local rice production meets only about 57% of the nation's annual demand of 6.5 million metric tons, resulting in a deficit of approximately 2 million metric tons (PwC, 2018).

In Nigeria, rice farmers are increasingly relying on agricultural scientists and extension officers for guidance on improving yields, managing pests, and selecting suitable rice varieties. However, these experts are often unavailable in remote areas when farmers need timely advice (Baig, 2005). To address this challenge, expert systems software

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applications that emulate human expert reasoning are being developed to assist farmers in decision-making processes (Baig, 2005). Developing a mobile-based expert system for rice production management can significantly enhance farmers' access to critical information, leading to improved decision-making and increased crop yields (Adedokun *et al*., 2020). Such systems integrate expert knowledge into user-friendly mobile applications, providing real-time guidance on various aspects of rice cultivation. Expert systems have become increasingly valuable in agriculture, particularly in diagnosing crop diseases and supporting decision-making processes. Globally, these systems have shown potential to enhance farming practices, especially in areas with limited access to extension agents. Expert systems have been widely applied across various agricultural areas, particularly for disease diagnosis and crop management decision-making.

These expert systems can be accessed via mobile phones, enabling farmers to receive real-time advice on issues such as disease diagnosis, pest control, and crop management. For example, a mobile-based expert system was created to diagnose rice diseases in real-time data from the field, making the diagnosis process faster and more accurate by allowing farmers to identify diseases based on observed symptoms and receive appropriate recommendations.

Digital agricultural tools can lead to changes in social practices and routines among smallholder farmers, suggesting that digitalization is not merely technical but profoundly socio-cultural (Abdulai et al., 2023).

Rice plays a central role in rural livelihoods and food security in Nigeria, serving as both a staple food and a key source of income for millions of smallholder farmers. Despite Nigeria's extensive arable land and diverse agro-ecological zones, rice productivity in many rural areas remains low compared to global benchmarks. Average yields of approximately 2.0–2.5 tons per hectare fall well below the global average and substantially below yields achieved in major rice-producing regions of Asia. This productivity gap reflects not only agronomic constraints but also broader structural challenges embedded within rural agricultural systems.

One of the most persistent challenges facing rural rice farmers in Nigeria is limited access to effective agricultural extension services. Public extension systems are often under-resourced, geographically uneven, and unable to provide timely, field-specific support, particularly in remote communities. As a result, farmers frequently rely on informal knowledge networks, personal experience, or trial-and-error approaches when responding to crop health problems. While such strategies reflect farmers' adaptive capacities, they also expose them to heightened production risks, especially in the case of crop diseases that require early and accurate diagnosis (Alih, 2024).

Crop diseases remain a major contributor to yield losses in rice production, with outbreaks of blast, bacterial leaf blight, sheath blight, and viral diseases significantly reducing output and income for smallholder farmers. In rural contexts where professional agronomic advice is scarce, disease symptoms are often misidentified, leading to inappropriate or delayed treatment. These challenges are compounded by low literacy levels, language barriers, and infrastructural limitations, which further constrain farmers' ability to access and apply formal agricultural knowledge (Ogunlela and Mukhtar, 2009).

In recent years, mobile digital technologies have emerged as important mediators of agricultural knowledge in rural areas of Nigeria. The widespread diffusion of mobile phones has created new possibilities for delivering advisory services beyond the physical reach of extension officers. However, many digital agricultural platforms prioritize information dissemination, such as weather updates or market prices, rather than interactive, problem-specific diagnostic support. Moreover, systems developed outside African contexts often fail to account for local disease ecologies, linguistic diversity, and everyday farming realities.

Within rural studies, there is growing recognition that technology adoption in agriculture is not merely a technical process but a socio-technical one, shaped by institutional arrangements, power relations, and everyday practices. Digital tools can function as complementary extension mechanisms, but their effectiveness depends on how well they are embedded within rural knowledge systems and adapted to local contexts. This perspective calls for empirical studies that examine not only technological functionality but also usability, accessibility, and relevance for rural users (Adedokun *et al*., 2020).

Responding to these challenges, this study examines the design and evaluation of a mobile-based expert system for rice disease diagnosis in rural Nigeria. Using a Design Science Research approach, the study develops *RiceAdvisor*, a rule-based expert system designed to support smallholder farmers by providing localized disease diagnosis and management recommendations through a mobile interface. Rather than positioning the system as a replacement for extension services, the study conceptualizes it as a socio-technical artifact that mediates access to expert knowledge where conventional extension support is limited.

The study addresses the following research questions:

(i) What types of diagnostic and management information do rural rice farmers prioritize?

(ii) To what extent are farmers willing to adopt a mobile-based expert system as an extension support tool?

(iii) How usable and contextually appropriate is the developed system for rural farming environments?

By foregrounding the lived realities of smallholder farmers and evaluating the system in real-world rural settings, this study contributes to rural studies and agricultural extension literature by demonstrating how digital advisory tools can be designed and evaluated as embedded components of rural knowledge infrastructures.

The Nigerian agricultural sector is dominated by smallholder farmers, most of whom operate without adequate support

from agricultural extension officers. Given the shortage and inaccessibility of experts in rural areas, farmers often rely on trial-and-error methods or outdated practices. This gap leads to delayed or incorrect disease diagnosis and mismanagement of rice crops, resulting in decreased productivity and increased post-harvest losses. Rice is a staple food for most of the Nigerian population, and its cultivation is vital for food security. Rice plants are susceptible to diseases that severely impact yield and quality. Farmers face challenges in accurately identifying these diseases due to similarities in symptoms and a lack of immediate access to agricultural experts. Misidentification leads to inappropriate treatment measures, exacerbating crop losses. There is a need for an accessible, reliable, and efficient diagnostic tool to help farmers identify rice plant diseases. Few expert systems developed in Nigeria are in English, and most farmers in Nigeria are less educated. Hence, the proposed expert system incorporates the local languages to help rural farmers diagnose rice plant diseases. The mobile-based expert system for rice disease diagnosis provide farmers with timely expert advice on disease identification and management, bridge the gap between farmers and agricultural experts through digital technology, and contribute to sustainable rice production and food security in Nigeria.

Contributions to Knowledge

Unlike generic agricultural advisory tools, this study presents a domain-specific expert system tailored to diagnose rice diseases commonly found in Nigeria. Additionally, many already developed systems lack contextual adaptation to the Nigerian farming environment, particularly regarding language, digital literacy, and regional disease prevalence. This study contributes new knowledge by developing a mobile-based expert system specifically designed for diagnosing rice diseases in Nigeria, while considering local agricultural practices, environmental factors, and user behavior among smallholder farmers. The system leverages mobile technology to provide real-time, location-independent access to expert-level recommendations. This addresses the limitations of physical extension services, especially in underserved rural areas, and ensures the continuous availability of diagnostic assistance to farmers. Unlike previous works that rely on generic datasets or simulation environments, this system integrates real-world farmer input, localized expert knowledge, and field-tested rule-based algorithms to deliver practical and accurate disease diagnostics. It also includes user-friendly AI-enhanced learning modules, tailored symptom queries, icon-based symptom selection, offline functionality, and multilingual support to accommodate varying literacy levels; these aspects, which are seldom addressed in prior research, have been integrated to improve usability and adoption among smallholder farmers. Furthermore, case studies from Nigerian rice-producing areas evaluate the system's usability, adoption potential, and diagnostic accuracy in real-world contexts. These elements present a novel, scalable, and impactful tool that supplements agricultural extension services, empowering farmers to make informed decisions and closing a critical gap in Nigeria's rice production management. This localized and applied approach significantly advances over the large contextual frameworks in the current body of literature.

Literature Review

Recent studies have emphasized that digital technologies are reshaping agricultural knowledge systems in ways that extend beyond technical efficiency. Rather than functioning as neutral tools, digital agricultural technologies are increasingly understood as socio-technical interventions that interact with existing rural institutions, social relations, and everyday farming practices. Empirical studies published in the Journal of Rural Studies highlight how digitalisation reconfigures farmers' routines, decision-making processes, and access to expertise, particularly in contexts where conventional extension services are limited (Abdulai et al., 2023).

In many rural areas of Nigeria, agricultural extension systems remain under-resourced and unevenly distributed, producing significant disparities in farmers' access to timely agronomic advice. Digital advisory tools have therefore been promoted as complementary mechanisms for strengthening extension delivery. However, rural studies scholars caution against techno-deterministic narratives, arguing that the effectiveness of digital tools depends on farmers' capacities, infrastructural conditions, and the extent to which technologies are embedded within local knowledge practices (Ingram & Maye, 2023).

Studies published in the Journal of Rural Studies further demonstrate that mobile technologies can enhance farmers' agency by enabling more autonomous decision-making, while simultaneously introducing new forms of dependency and exclusion. Issues such as literacy, language, trust in digital recommendations, and institutional support shape how rural users engage with agricultural technologies (Abdulai et al., 2023). These insights underscore the need for applied research that evaluates not only the functionality of digital advisory systems but also their usability, contextual relevance, and integration into rural livelihoods.

Building on this body of work, the present study conceptualizes a mobile-based expert system as a socio-technical extension artifact designed to mediate access to rice disease diagnostic knowledge among smallholder farmers in rural Nigeria. By grounding system design in farmers' expressed needs and evaluating its usability in real-world rural contexts, the study responds directly to calls within rural studies for empirically informed assessments of digital agricultural interventions (Ingram & Maye, 2023).

In the global agricultural research community, the diagnosis of diseases in rice plants has been a critical area of study due

to rice's role as a staple food for more than half of the world's population. Disease outbreaks such as rice blast, bacterial leaf blight, sheath blight, and brown spot have caused significant yield losses, sometimes reducing harvests by up to 30–50% in severely affected areas.

Several studies and initiatives have shown that mobile and digital technologies can be effective for extension service delivery. Dlodlo and Kalezhi (2015) noted that widespread adoption of mobile phones in rural areas has created unprecedented access to information and advisory services for farmers and significantly improved information dissemination among farmers, particularly those in remote communities. These platforms, however, often focus on general advisory services and do not provide specific, real-time diagnostic capabilities for crop diseases.

Notably, the mAgri app in Kenya, which allows farmers to access market information, weather updates, and agronomic tips, leads to increased participation in agricultural markets [9]. However, it lacked interactive expert decision support features, which limited its capacity to diagnose and respond to specific crop health issues. Another example is the Esoko platform in Ghana, which offers up-to-date agricultural market prices, weather forecasts, climate-smart agricultural advisories, and agronomic advisory content and combines SMS, IVR, and voice messaging in local languages, enabling farmers to receive personalized advice, thus boosting their efficiency in agriculture by making well-informed decisions (Sarku *et al*., 2021).

A study by Grunfeld and Houghton [11] emphasized the integration of ICT tools into agricultural systems to improve climate adaptation strategies and scale organic inputs. They suggested that expert systems could serve as climate-resilient advisory tools to mitigate the effects of plant diseases exacerbated by erratic weather patterns. Eleke *et al*. (2024) emphasized the importance of ICT in agricultural transformation, underscoring the need for intelligent systems that provide expert-level support, thereby enabling farmers to optimize their agrarian practices by facilitating the transfer of information across different locations.

Several intelligent systems have been developed to identify rice diseases using various artificial intelligence approaches, including rule-based systems, image processing, and machine learning approaches. Benali and Boukhalfa's mobile-based expert system was developed for diagnosing rice diseases, incorporating forward chaining algorithms alongside real-time data integration from IoT sensors and GPS-enabled devices. The system's knowledge base was built from information gathered from agricultural experts and research literature. Field trials on ten farms showed that the system achieved high diagnostic performance, with 97.01% accuracy, 90.69% sensitivity, and 85.37% specificity.

Other researchers have adopted visual and pattern recognition models to automate disease detection. For example, Naresh Kumar and Sakthivel (2025) introduce an innovative approach for detecting rice diseases by leveraging the fusion vision boosted classifier (FVBC), which integrates VGG19 for feature extraction and LightGBM for classification. The model offers a non-invasive and scalable approach for early detection of rice diseases, enabling farmers to take timely action and enhance overall crop productivity. While highly promising, these systems require high-resolution images and consistent lighting, which may limit their effectiveness in field conditions typical of rural Africa.

Recent advancements in artificial intelligence (AI) and machine learning have significantly enhanced the diagnosis of diseases in rice plants. These technologies offer promising solutions to challenges faced by farmers, particularly in regions like Nigeria, where access to extension agents may be limited.

Deng *et al*. (2021) developed a methodology using deep learning on a dataset of 33,026 images of six various kinds of rice diseases, which was integrated in a smartphone app. An accuracy of 91% was achieved. The study employed a deep learning model, such as CNN, to analyse images of rice leaves and identify various diseases. The goal is to equip farmers with a simple yet reliable tool for the early detection of rice diseases, helping them manage outbreaks promptly and minimize crop losses.

Bari *et al*. (2021) utilized Faster R-CNN algorithm for real-time detection of rice leaf diseases with over 99% accuracy for multiple disease types such as brown spot, leaf blast, and Hispa diseases, showcasing the potential of deep learning in precise disease identification. Using a self-constructed database and Kaggle, the models were assessed with 2400 images.

Li *et al*. (2023) reviewed image processing techniques using machine learning and deep learning models related to multi-scale rice diseases, summarizing applications of different detection techniques, including genomic, physiological, and biochemical approaches. Recent developments in disease detection technologies have demonstrated the strong potential of machine learning and deep learning models, achieving remarkable accuracy in diagnosing rice diseases and paving the way for smarter, data-driven agricultural solutions.

These studies underscore the potential of AI-driven expert systems in enhancing rice disease diagnosis. Nevertheless, there remains a critical need for context-specific solutions that address the unique agronomic conditions and operational challenges encountered by Nigerian rice farmers. Developing mobile-based expert systems that incorporate local disease profiles and farming practices can bridge this gap, offering accessible and effective tools for disease management.

Overall, while there have been commendable efforts to integrate ICT into Nigerian agriculture, few systems are designed specifically for rice disease diagnosis with real-time mobile-based functionality. The current study fills this gap by providing a tailored, farmer-friendly expert system that leverages local knowledge and digital infrastructure to improve rice health management and boost productivity.

Existing Mobile-Based Expert Systems for Rice Production

Several mobile applications have been developed to assist rice farmers. This includes:

- **riceXpert**: Developed by the ICAR-National Rice Research Institute, this app offers comprehensive information on rice cultivation practices, pest and disease management, and post-harvest technologies.

- **TNAU Paddy Expert System**: Created by Tamil Nadu Agricultural University, this Android application provides detailed guidance on paddy cultivation, including variety selection, nutrient management, and pest control. User feedback has been analyzed to enhance its effectiveness.

- **Rice Doctor**: Developed by the International Rice Research Institute (IRRI), this mobile app is an interactive diagnostic tool developed to diagnose insect pests and diseases and enables farmers to make timely decisions for better pest management.

Despite these technological advancements, there is a significant gap in the literature and applications focused on African and Nigerian agricultural contexts. Most rice disease expert systems are developed and tested in Asian countries with different environmental conditions, disease variants, and farming practices. Thus, there is a pressing need to localize such technologies by training the systems on data from Nigerian rice fields and tailoring the interface to local languages and usage patterns.

Materials and Methods

The expert system is designed using a rule-based approach and developed for mobile devices to maximize accessibility. The study took a methodical approach that integrated knowledge-based system development with Design Science Research (DSR) in the planning and implementation of a mobile-based expert system for diagnosing rice diseases. The approach used sought to ensure that the developed artefact had both technical credibility and real-life farming relevance to the field. The sample included 50 smallholder rice farmers who owned smartphones, using purposive sampling and a structured questionnaire.

Requirement Gathering for the Mobile-Based Expert System

To answer the research question, data were collected using a semi-structured questionnaire. The respondents interviewed comprise rice farmers in Zaria, Ibadan, and Umudike. These locations are in Kaduna, Oyo, and Abia states, respectively.

To select the participants, both random and purposive sampling techniques were employed. A total of 90 respondents were randomly chosen from each location, resulting in a sample size of 270. The data was analysed using the IBM Statistical Package for Social Sciences (SPSS) version 26 to generate descriptive statistics.

The study also examined the farmers' willingness to adopt the mobile-based expert system. It was found that 129 respondents (47.78%) strongly supported adopting the system, while only 5 respondents (1.85%) were opposed to it, as shown in Table 1.

Table 1: Willingness to Adopt an Expert System (n=270)

Willingness to Adopt ES	Frequency	Percentage
Strongly Disagree	5	1.85
Disagree	9	3.33
Neutral	12	4.44
Agree	115	42.59
Strongly Agree	129	47.78

Source: Author's Field Survey, 2025

Table 2 shows the information needed by the respondents. This further reveals that 74.07% of the respondents need information on crop disease diagnosis and management, 57.78% need information on fertilizer application, 56.67% need information on irrigation techniques, and 44.44% need information on early warning for disease outbreak.

Table 2: Information Needs of Rice Farmers (n=270)

Information Need*	Frequency	Percentage
Crop disease diagnosis and management	200	74.07
Fertilizer application	156	57.78
Irrigation technique	153	56.67
Nursery management	91	33.70
Pesticide usage and safety	100	37.04
Early warning information	120	44.44
Market price information	98	36.30

Source: Author's Field Survey, 2025– *Multiple Responses

Therefore, the most crucial information for rice farmers focuses on diagnosing and managing crop diseases. In response to this need, a mobile-based expert system was developed to assist in diagnosing diseases in rice plants.

Design Science Research Approach

This study adopts a Design Science Research (DSR) methodology to guide the systematic development and evaluation of a mobile-based expert system for rice disease diagnosis. DSR is particularly suitable for this research because it focuses on the creation and evaluation of IT artifacts designed to address real-world problems while

simultaneously contributing to scientific knowledge through rigorously grounded design principles.

Following established DSR guidelines, the study progressed through five interrelated phases: problem identification, objective definition, artifact design and development, demonstration, and evaluation.

Problem Identification and Motivation

The research problem was identified through field observations, literature review, and stakeholder engagement with rice farmers and agricultural extension practitioners in Nigeria. Persistent challenges such as delayed disease diagnosis, limited access to extension services, and misapplication of disease control measures were found to significantly constrain rice productivity. These challenges are exacerbated in rural areas where expert support is scarce, motivating the need for a digital diagnostic artifact accessible via mobile devices.

Definition of Objectives for the Solution

Based on the identified problem, the objectives of the proposed artifact were defined as follows:

a To provide accurate and timely diagnosis of common rice diseases prevalent in Nigeria;
b To deliver actionable management recommendations using expert knowledge;
c To ensure accessibility under constraints of low digital literacy and intermittent internet connectivity;
d To support agricultural extension through a scalable and context-aware mobile solution.

Design and Development of the Artifact

The core artifact developed in this study is RiceAdvisor, a mobile-based expert system implemented using a rule-based reasoning approach. Knowledge acquisition involved collaboration with agricultural experts, review of agronomic literature, and synthesis of localized disease profiles. Diagnostic knowledge was encoded as IF–THEN rules within a structured knowledge base.

The system architecture comprises three principal components: a knowledge base, an inference engine employing forward-chaining reasoning, and a multilingual user interface designed for ease of use by smallholder farmers. The application was implemented on the Android platform to maximize accessibility and includes offline diagnostic functionality to address connectivity limitations.

Demonstration

The artifact was demonstrated through real-world use scenarios involving rice farmers in selected rice-producing communities in Kaduna, Oyo, and Abia States. Farmers interacted with the system by selecting observed symptoms, after which the expert system generated disease diagnoses and corresponding management recommendations. This phase established the feasibility of the artifact in operational farming environments.

Evaluation

Artifact evaluation focused on **usability, perceived usefulness, and practical relevance**, consistent with DSR evaluation principles. A System Usability Scale (SUS) questionnaire was administered to 50 farmers who used the system. The resulting mean SUS score of 76.5 indicates acceptable to good usability, suggesting that the artifact effectively meets user needs and design objectives. Comparative evaluation with related systems further demonstrates the artifact's contribution to applied agricultural informatics in resource-constrained settings

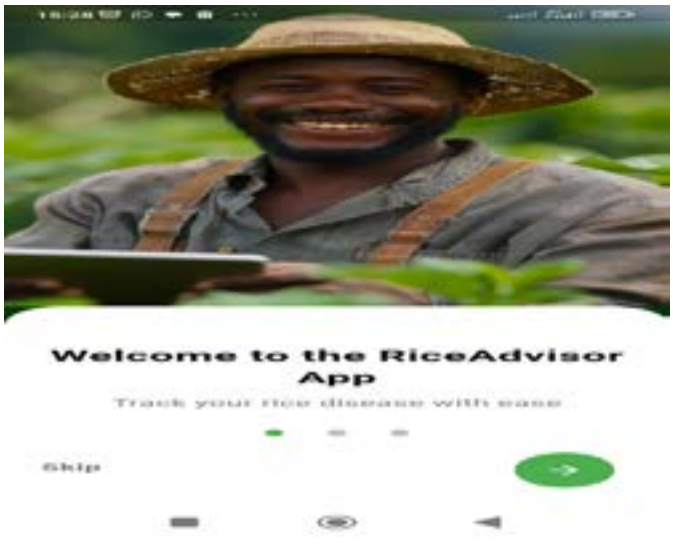

Figure 2: RiceAdvisor Homepage

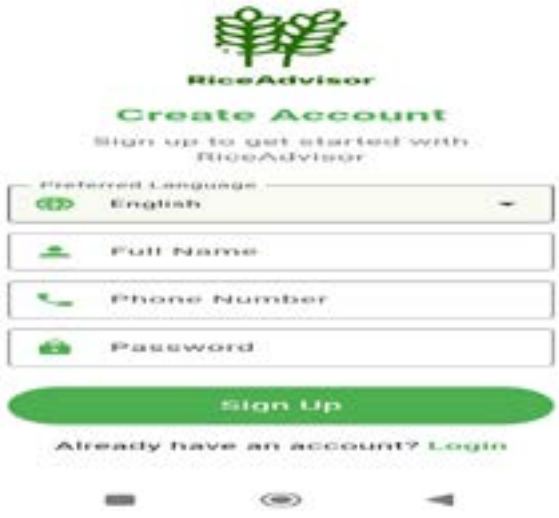

Figure. 3: User Login Interface

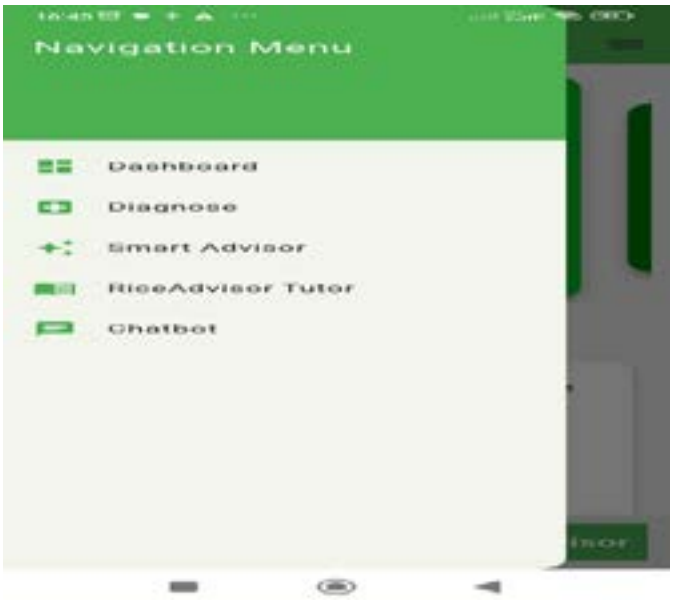

Figure 4: Navigation Menu Interface

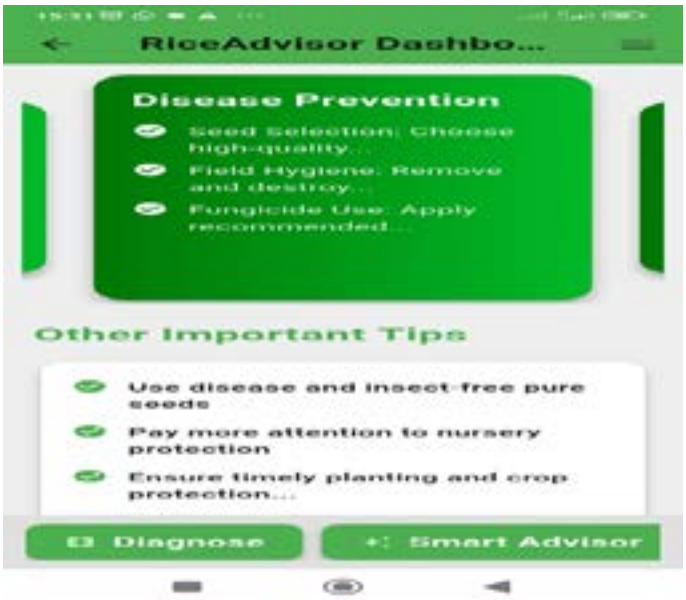

Figure 5: Tips on Disease Prevention Interface

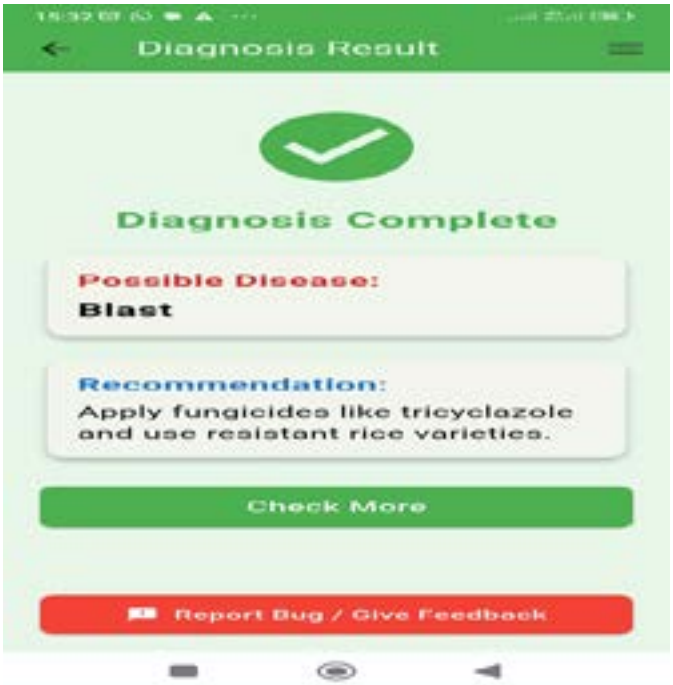

Figure 6: Diagnosis Result Interface in English

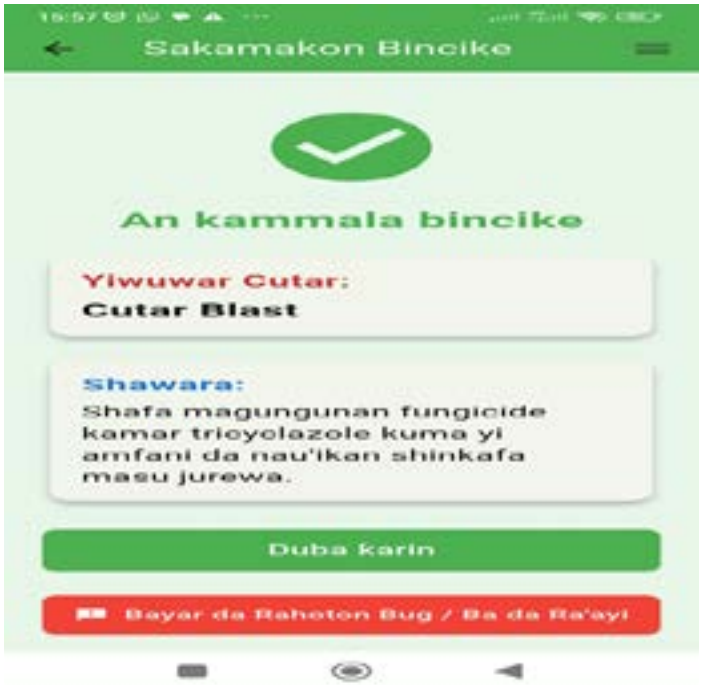

Figure 7: Diagnosis Result Interface in Hausa

Results and Discussion

The usability assessment of the RiceAdvisor, conducted using the System Usability Scale (SUS), produced a mean score of 76.5. This places the system within the "Acceptable Usability" category, as defined by established SUS guidelines, and slightly above the widely accepted average benchmark of 68 (Zheng *et al.*, 2024). This score indicates that users found the system sufficiently usable and satisfactory for practical application. Given the system's purpose to support intelligent rice farming, this outcome is encouraging and suggests the RiceAdvisor App holds promise as a functional tool for agricultural extension services. The usability findings highlight the system's accessibility and adaptability to different user profiles. A SUS score of 76.5 signals accomplishment of user-centered design principles and success relative to Okai *et al.* (2025), whose score was 70.025. Therefore, the RiceAdvisor's score reinforces its feasibility as a digital innovation for addressing the knowledge and resource gaps faced by rice farmers.

From a rural studies perspective, the usability and adoption of the RiceAdvisor system reflect broader dynamics of digital

mediation within rural knowledge systems. Consistent with findings reported in the *Journal of Rural Studies*, the system's perceived usefulness is shaped not only by its technical performance but by its alignment with farmers' everyday practices, linguistic preferences, and infrastructural constraints (Abdulai et al., 2023). Features such as offline functionality and multilingual interfaces enhance inclusivity and reduce barriers to engagement, reinforcing arguments that digital agricultural tools must be designed around rural capacities rather than assumed technological readiness.

Moreover, the system illustrates how digital advisory tools can function as complementary extension mechanisms within hybrid rural governance arrangements. Rather than replacing extension officers, the expert system operates as a mediating artifact that redistributes access to agronomic knowledge across spatial and institutional gaps. This finding aligns with rural studies that emphasizes the growing pluralisation of extension systems, where knowledge is increasingly co-produced through interactions among farmers, digital platforms, and formal institutions (Ingram & Maye, 2023).

At the same time, the study highlights the importance of institutional embedding for sustained impact. As argued in recent studies' contributions, digital tools that are not supported by broader extension frameworks risk becoming isolated interventions with limited long-term influence on rural livelihoods (Abdulai et al., 2023). These findings reinforce the need for policy approaches that integrate digital advisory systems into national extension strategies while remaining attentive to rural inequalities and context-specific constraints.

Conclusion and Future Work

This study has examined the design and evaluation of a mobile-based expert system for rice disease diagnosis as a socio-technical intervention within rural agricultural contexts in Nigeria. Using a Design Science Research approach, the study demonstrated how a digital advisory artefact can be developed to address persistent gaps in agricultural extension services, particularly for smallholder farmers operating in resource-constrained rural environments. Rather than focusing solely on technical performance, the system was designed to align with farmers' everyday practices, linguistic diversity, and infrastructural realities.

The findings indicate that mobile-based expert systems can play a complementary role in rural extension systems by mediating access to agronomic knowledge where conventional advisory services are limited or unevenly distributed. By enabling early and accurate disease diagnosis, the system supports farmers' decision-making capacity and enhances their ability to respond proactively to crop health challenges. In this sense, the expert system functions not as a replacement for extension officers, but as a distributed extension artefact that extends expert knowledge across spatial and institutional boundaries.

From a rural studies perspective, the study contributes empirical evidence on how digital technologies can be embedded within rural knowledge systems to support agricultural livelihoods. The positive usability outcomes suggest that when digital tools are designed with attention to local contexts, such as language, literacy, and connectivity, they can enhance farmers' confidence, autonomy, and engagement with agronomic knowledge. However, the study also highlights that the long-term impact of such systems depends on their integration into broader institutional and policy frameworks governing agricultural extension and rural development.

Future research should therefore move beyond technical enhancement alone to examine how digital advisory tools can be sustainably embedded within rural extension infrastructures. While the integration of real-time environmental data, sensor technologies, and machine learning techniques may improve diagnostic flexibility and accuracy, equal attention should be given to issues of institutional support, trust, governance, and inclusivity. Longitudinal studies assessing sustained use, farmer learning outcomes, and interactions between digital tools and extension actors would provide deeper insights into the role of mobile expert systems in shaping rural agricultural futures.

Overall, this study underscores the potential of context-aware digital advisory systems to contribute to more resilient and inclusive rural agricultural development when designed and evaluated as part of the broader socio-technical landscape of rural livelihoods.

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