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Original Study

A mobile application for agricultural market integration in Luwero District. A cross-sectional study.

Eseza Nakayima, Aloyzious Ssenteza*, Hillary Tumwesigye
Faculty of Business and ICT, University of Kisubi.

Abstract

Background:

This study aimed to develop a mobile application that enhances agricultural market integration by addressing the information asymmetry, limited access to buyers, and logistical challenges that farmers face.

Methodology:

A cross-sectional study design was employed using qualitative methods to collect data from approximately 40 purposively selected participants, including smallholder farmers, market vendors, agricultural officers, ICT experts, and farmer cooperative representatives. Data were collected using interviews, questionnaires, observations, focus group discussions, and document review. Findings informed the design and development of a hybrid mobile application using Progressive Web Application (PWA) technology, Android Studio, Java, and Supabase. The system underwent unit, integration, system, acceptance, and performance testing.

Results:

The study identified major weaknesses in the existing manual marketing system, including delayed market access, high transaction costs, insecure transactions, and limited geographical reach. UnikAgric was developed with features such as secure user authentication, product listing and management, real-time messaging, product search, and offline PWA functionality. User evaluation showed high acceptance, with **75%** rating the application as very useful, **80%** finding it easy to use, and **90%** reporting that the user guidelines were helpful. Additionally, **53%** of respondents preferred mobile applications over websites for accessing agricultural market information. The application successfully enabled direct communication between farmers and buyers while improving access to market information.

Conclusions:

UnikAgric effectively addresses key agricultural marketing challenges by providing a scalable, user-friendly digital platform that strengthens market integration, reduces reliance on intermediaries, and improves access to buyers and market information.

Recommendations:

The application should be scaled to other districts and enhanced through integration of mobile money payments, advanced search filters, user ratings, multilingual support, stronger offline functionality, and logistics services. Future studies should evaluate its long-term impact on farmers' incomes and market participation.

Keywords: *Mobile application, Agricultural market integration, Luwero District.*
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Corresponding author: *Aloyzious Ssenteza*
Email:*assenteza@unik.ac.ug*
Faculty of Business and ICT, University of Kisubi.

Background of the Study

Agriculture remains the backbone of Uganda's economy, employing over 70% of the population, most of whom are smallholder farmers (UBOS, 2023). However, despite its significance, the agricultural sector in Uganda continues to face critical challenges, particularly in market access and integration. Farmers in rural districts like Luwero often lack timely and reliable information on market prices, demand trends, and potential buyers, which leads to low bargaining power, post-harvest losses, and exploitation by middlemen (FAO, 2019).

Market integration is a vital component of agricultural development, as it connects producers with consumers, enables fair pricing, and promotes income stability. According to the World Bank (2023), digital technologies such as mobile applications have the potential to transform

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rural agriculture by improving access to market information, enabling direct linkage between farmers and buyers, and fostering transparency in transactions. In recent years, the adoption of mobile phones in rural Uganda has significantly increased, offering a viable platform for deploying mobile-based solutions to enhance agricultural marketing (GSMA, 2021).

Several mobile applications have been introduced in Uganda to support agriculture, including platforms like AgriConnect, e-Soko, and M-Omulimisa. However, their penetration and effectiveness vary greatly across regions due to differences in digital literacy, infrastructure, and relevance to local needs. In the Luwero District, a region with a significant number of smallholder farmers, limited access to localised digital market integration tools continues to constrain agricultural productivity and income generation.

The development of a tailored mobile application for market integration in Luwero aims to bridge this digital gap by providing a user-friendly, real-time platform for price updates, buyer-seller interaction, weather alerts, and transport logistics. This initiative aligns with Uganda's Digital Transformation Roadmap 2023–2027, which emphasises the role of ICT in promoting inclusive growth and sustainable development.

This study aimed to develop a mobile application that enhances agricultural market integration by addressing the information asymmetry, limited access to buyers, and logistical challenges that farmers face.

Methodology

Study design

A cross-sectional study design was employed, which focused on Luwero District as a representative rural farming community in Uganda. This approach allowed for detailed investigation of existing agricultural marketing practices and the design, development, and evaluation of a mobile application in a real-world setting. The study used qualitative and quantitative methods to explore the experiences, challenges, and needs of smallholder farmers regarding agricultural market access.

Study Population

The study population comprised smallholder farmers, local market vendors, agricultural officers, ICT specialists, and representatives from farmer cooperatives in Luwero District. This population was targeted because they are directly affected by market access challenges and stand to benefit from the proposed system.

Sample size determination

A sample of approximately 40 participants was selected from the study population. These included: 25 smallholder farmers from different sub-counties, 5 agricultural officers, 5 market vendors/traders, 3 ICT experts, and 2 representatives from local farmer cooperatives.

Sampling methods

The study used purposive sampling to select participants with relevant knowledge and experience in agricultural marketing. Farmers were chosen based on their active engagement in crop production and interest in market integration. ICT experts were selected based on their experience in system development and usability design.

Sampling frame

The sampling frame consisted of registered smallholder farmers and agricultural actors in Luwero District, obtained from the District Agricultural Office. This ensured that the sample was representative of the local agricultural ecosystem.

Data collection methods and instruments

Data were collected using the following instruments:

Semi-structured interviews with farmers, agricultural officers, and traders to gather information on current practices and challenges.

Observation checklists to record farmer activities, market transactions, and communication methods.

Document analysis to review agricultural reports and existing digital tools.

Validity of instruments

To ensure validity, data collection instruments were reviewed by experts in agricultural extension and ICT. A pilot test was also conducted in one sub-county to refine the interview questions and ensure clarity, relevance, and comprehensiveness.

Research procedure

The research was conducted in four main phases:

Preliminary study to assess the current agricultural marketing systems.

Data collection through interviews and FGDs.

System design and development based on the identified requirements.

System testing and evaluation with selected users.

Data analysis

Qualitative data from interviews and focus group discussions were analysed using thematic analysis. Patterns

and themes were identified to guide system requirements and inform design decisions. Results were coded, categorised, and interpreted based on relevance to market integration and user needs.

Ethical considerations

Ethical approval was obtained from the relevant authorities. Participants were informed about the purpose of the study and gave informed consent before participating. Privacy and confidentiality were maintained, and participation was voluntary. Data were anonymised and stored securely.

System design tools and methods

The system was designed using the Object-Oriented Analysis and Design (OOAD) approach. Tools used included:
UML diagrams (use case diagrams, class diagrams, activity diagrams)
Wireframes for user interface design
Entity Relationship Diagrams (ERDs) for database modelling
Design principles such as user-centred design, simplicity, and accessibility guided the development process.

System implementation

The mobile application was implemented using Android Studio with Java/Kotlin for the frontend and Firebase/MySQL for the backend services. Features included: real-time price updates, buyer-seller communication, crop listing and search, and transport coordination alerts.

System testing methods

The system was tested using the following methods:

- Unit Testing to ensure each component of the application works correctly.
- Integration Testing to verify that modules function properly when combined.
- User Acceptance Testing (UAT) with selected farmers and agricultural officers to assess usability, relevance, and satisfaction.
- Performance Testing to evaluate responsiveness and load handling of the app under different conditions.

Results from testing

Weaknesses of the existing manual systems.

The development of UnikAgric was motivated by the inefficiencies of traditional agricultural market systems:

- **Access Time:** Manual systems are time-consuming. Finding market information, price data, or connecting with buyers/sellers can be a slow process for farmers.
- **Lack of Security:** Physical transactions and informal agreements lack the security and traceability of a digital platform.
- **Higher Cost:** Intermediaries in the traditional system often increase costs for the end consumer while reducing the farmer's profit margin.
- **Geographical Limitations:** Manual systems are constrained by physical location, limiting a farmer's market reach and a buyer's options.

Proposed system.

The UnikAgric application is a hybrid system. At its core is a **progressive web app (PWA)** designed to function seamlessly on mobile. This PWA is then wrapped in a **native Android application**, allowing it to be distributed through app stores and to better integrate with the mobile operating system. It serves as a digital marketplace that directly connects farmers (sellers) with buyers, agricultural experts, and veterinarians.
The application provides a centralised platform where farmers can showcase their products by uploading images, quantities, and prices. Buyers can browse this digital marketplace, view product details, and directly communicate with sellers through an integrated real-time chat feature.

Key features of the proposed system include:

- **User Authentication:** Secure registration and login for all users.
- **Product Management:** Farmers can create, update, and delete their product listings.
- **Real-time Chat:** A built-in messaging system allows for direct negotiation and communication between buyers and sellers.
- **Native Device Integration:** The Android wrapper allows the app to access native features like the camera and file storage for a smoother user experience.
- **Community Connection:** The platform fosters a community, enabling users to exchange vital information regarding best agricultural practices and market trends.
- **PWA Functionality:** As a PWA, UnikAgric is installable on devices directly from the browser, offers offline capabilities, and sends real-time push notifications.

System Study and Analysis

This research applied both qualitative and quantitative research techniques in collecting and analysing data.

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Data was collected from vendors in Luwero district. Questionnaires and interview guides were used to collect data from different individuals, which was later analysed quantitatively using descriptive analysis.

Results from Interviews

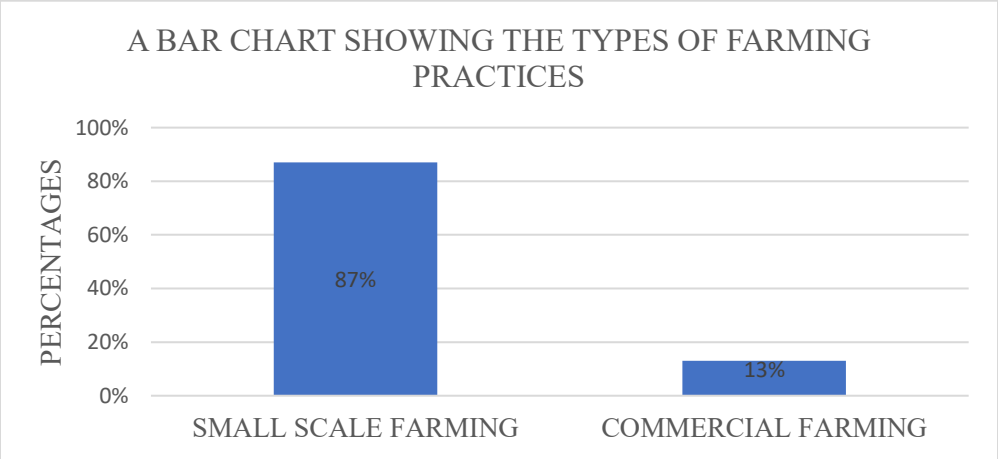
While carrying out the research, we were able to interview the vendor from Nakasero Market.
These helped us get a deeper understanding of the challenges faced while differentiating counterfeit inputs from genuine ones, as many stated that they look so alike that you can hardly differentiate them until you use them.

Results from Questionnaires

The Types of Farming Practices.

When we asked the farmers the types of farming practices they perform, they informed us that many of the farmers practice small-scale farming, about 87% of them, and 13% of farmers practice commercial farming, as shown in the bar chart below.

Figure 1: Showing a bar chart of the types of farming practices.



The Farmers' Experience After They Used the Counterfeit Farm Inputs in Their Farms.

When we asked the farmers what their experience was when they used the counterfeit Inputs in their farms, these were some of their responses:

- The rest of the livestock did not die.
- One female participant said that after she used the counterfeit inputs, she made a loss because the insects that she wanted to die never died.
- Another female participant said that when she used the counterfeit inputs, it was bad because all her farming inputs did not germinate.
- One male participant said that after he used the counterfeit products, the soil lost its fertility, leading to low farm produce.

What Are the Challenges Farmers Face Using the Above Methods to Verify Counterfeit Inputs

After asking the farmers how they verify the inputs we asked them about the challenges they face when verifying the farm inputs, we were informed that 26% of the farmers said that the inputs come with broken seals claiming it was damaged on the way, 61% of farmers said that some expiry dates are scratched off or are not included by the manufacturer, 13% of the farmers said that some people do not have smart phones that can scan codes and none selected the option of systems not being reliable and that they don't give valid information. This is shown in the pie chart below.

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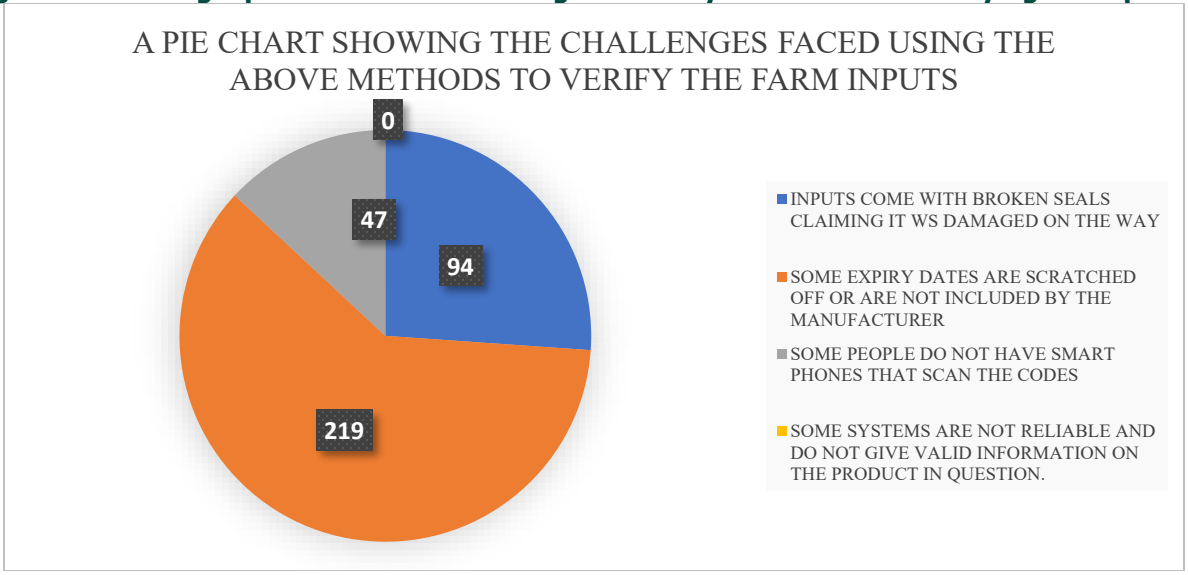
Figure 2: Showing a pie chart of the challenges faced by farmers when verifying the inputs



Recommendations from the Farmers.

System Approval

When we asked the farmers if they recommend a new UnikAgric to search and receive information about the inputs they have in question, they all said YES and agreed to start using the UnikAgric.

System Functionality

We asked the farmers the functionalities they would like to encounter on the system, and they mostly chose the function "search for the best farm inputs", followed by "register farmers and retailers", then "manage users", then verify farm inputs and the login and logout came last.

Preferred Application

When we asked the farmers the best way to keep them updated about the information concerning the inputs on the market, these are the responses: 53% of the farmers preferred to use a phone application/ mobile application to help them search and receive information about the valid and counterfeit farm inputs. 47% of the farmers preferred to use a website, though we have decided to use both such as to benefit everyone.

System Requirements

With the study of collected data as well as literature about the current UnikAgric, this helped us determine the different requirements needed for our UnikAgric. The requirements are grouped into user, functional, and non-functional requirements.

User Requirements

These show what services the system is expected to provide to system users and constraints under which it must operate.

User (Farmer/Seller/Buyer):

- Should be able to register for an account and log in/out.
- Should be able to create, view, update, and delete their own profile.
- Should be able to list products for sale with details and images.
- Should be able to browse and search for products.
- Should be able to view product details and seller information.
- Should be able to initiate real-time chats with other users.
- Should be able to send and receive messages.
- Should be able to save products to a 'Favourites' list.

Administrator:

- (Via Supabase Dashboard) Should be able to manage user accounts (create, delete, update).
- (Via Supabase Dashboard) Should be able to moderate content, including product listings and user profiles.
- (Via Supabase Dashboard) Should be able to view system-wide data and generate reports.

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Functional Requirements

These show the services that an application should provide, how an application should react to certain input, and how an application should behave in particular situations. These are the functional requirements of UnikAgric.

- Must have a database
- Must have a client interface for farmers to allow them to sign in
- Must have an administrative interface where the administrator can add and delete accounts.
- Must produce summary reports from analysis and calculations
- Must run free of errors on popular technical environments
- Must have a view functionality to allow normal or privileged users to view details

Non-Functional requirements

These are constraints on services or functions offered by an application and apply to an application as a whole rather than individual features of an application. These include;

- Availability: an application shall be available at all times
- Security: an application shall ensure effective security measures such as authentication and authorisation
- Should be able to minimise errors as much as possible
- Data integrity: an application shall maintain data integrity for all users
- Should respond to user requests in the shortest time possible, preferably a minute in case of extreme delays
- Should be easy to use and learn even for users with limited computer skills

System Requirements

Hardware requirements

Table 1: Showing the Hardware requirements for the UnikAgric

ITEM	MINIMUM REQUIREMENT
Processor	Intel Pentium
Memory	512MB RAM
Hard Disk Space	10GB HDD Space
Processor Speed	1GHZ

Software requirements

Table 2: Showing the Software requirements for UnikAgric

ITEM	MINIMUM REQUIREMENT
Operating System	Windows
Web Browser	Mozilla, Google Chrome
Database Management System	MySQL
Microsoft Office	Word, Excel and Visio

System Design

Process Modeling

In process modeling, we looked at the visual presentation and documentation of information flows within UnikAgric. The different structures in this report show how the information enters and leaves an application, changes in the information, and where it is stored. With this, we can show the scope and boundaries of an application as a whole.

Context Diagram

The UnikAgric system operates by facilitating interactions between **Users** and the **Supabase Backend** through a hybrid mobile application.

- **Users (Farmers/Buyers)** interact with the native Android App.

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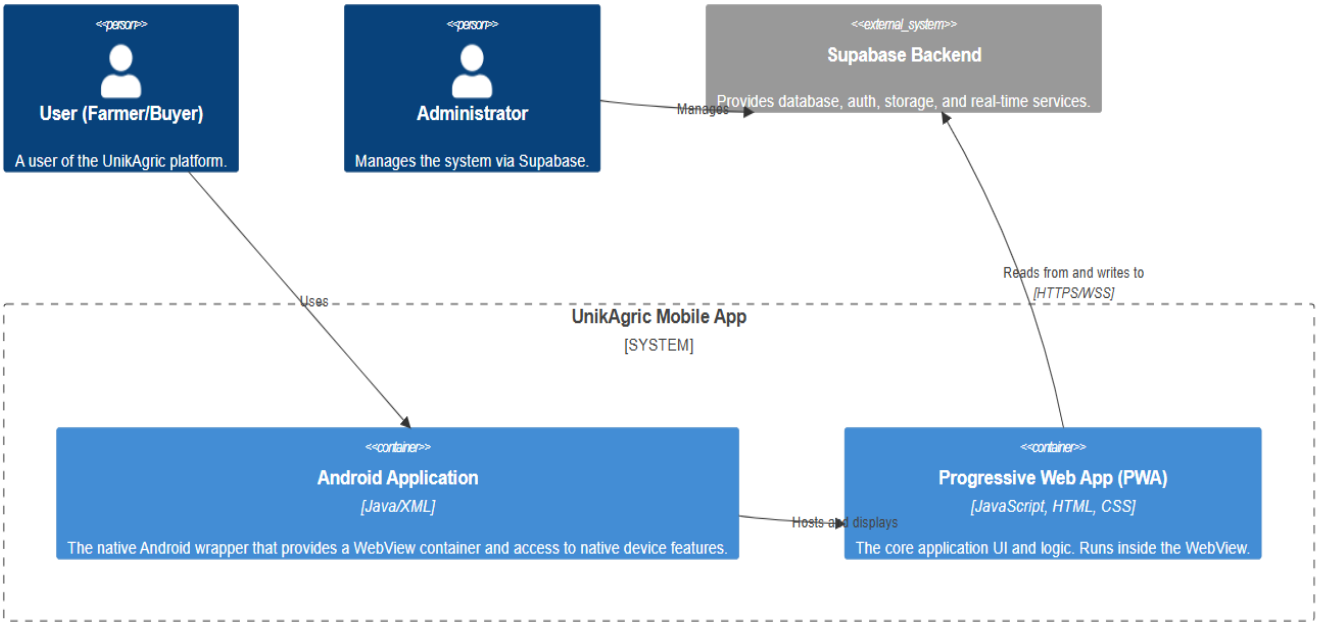
- The **Android App** acts as a container, hosting the PWA in a WebView and providing access to native device features.
- The **UnikAgric PWA** contains the core UI and application logic, processing user requests and interacting with Supabase.
- The **Supabase Backend** handles all core logic: authentication, database queries, file storage, and real-time communication.
- An **Administrator** interacts directly with the Supabase Backend through its dashboard for management and moderation tasks.

Figure 3: Context Diagram for the UnikAgric application



Level 1 Data Flow Diagram

This diagram illustrates the high-level processes and user flows within the application.

1. **Manage Authentication:** Handles user registration, login, and session validation. It receives credentials and returns a user session.
2. **Manage Profile:** Allows users to create and update their profile information, which is stored in the database.
3. **Manage Products:** Handles the creation, updating, deletion, and viewing of product listings. This process interacts with both the database (for text data) and storage (for images).

Facilitate Communication: Manages the sending and receiving of real-time messages between users.

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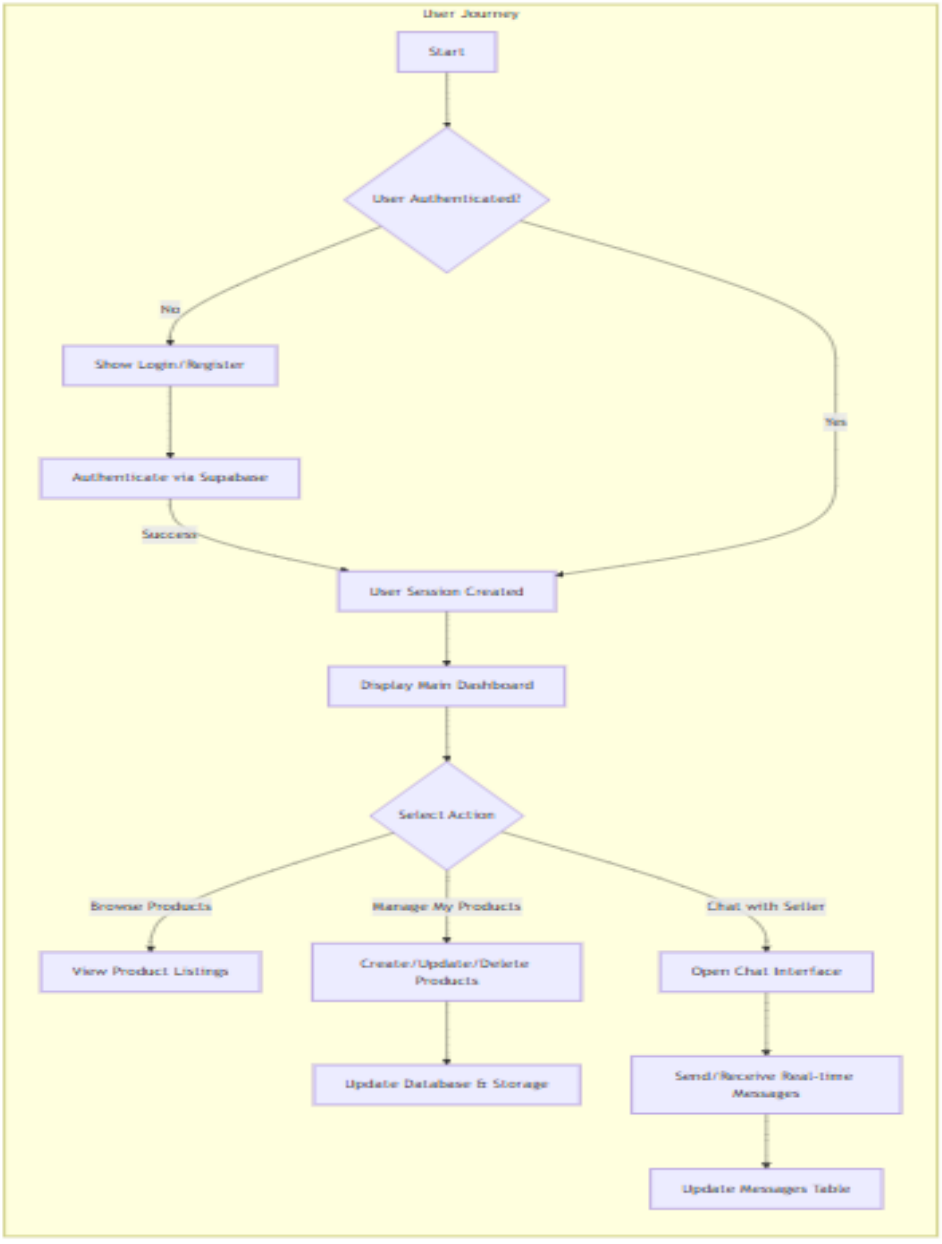
Figure 4: Showing Level 1 Data Flow Diagram.



Sequence Diagram: Real-Time Chat

This diagram shows the sequence of events when a user sends a chat message to another user.

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Figure 5: Sequence Diagram: Real-Time Chat

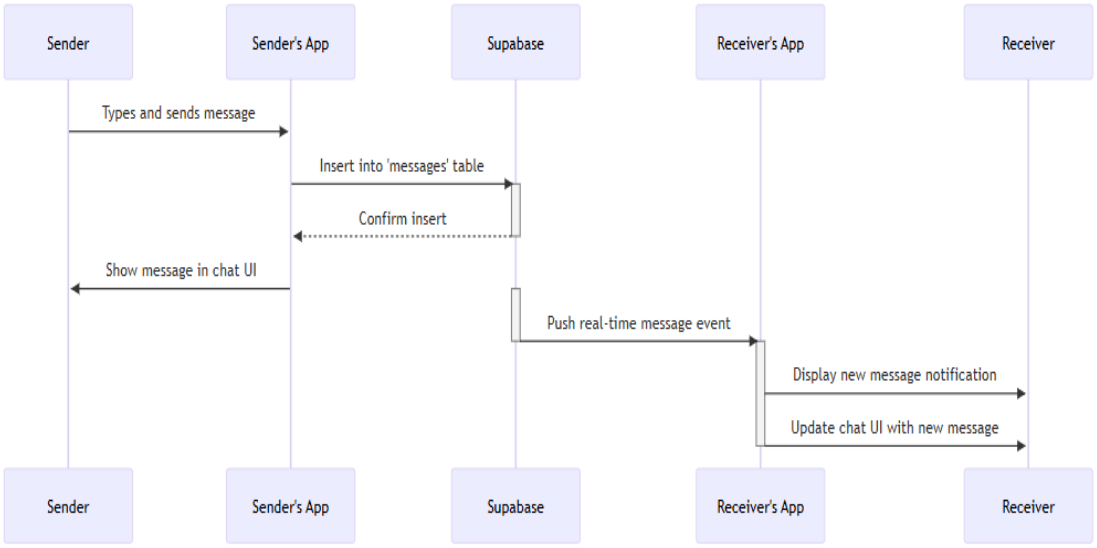

Table 3: Showing the System Processes

Process	Description
1: Register users	The application receives the data entered by the Administrator for all the users that request accounts on the application.
2: Authenticate User	The application receives login credentials and confirms that they are correct; then the user is given access to the application.
3: Check for Valid Farm Inputs	The system captures data about the valid farm Inputs from the different clients and veterinarians.
4: Access Information on Farm Inputs	The application provides access to the information about the valid farm Inputs in the application.
5: Access contacts about the clients and veterinarians	The application generates information about the clients' and veterinarians' telephone contacts and their location.

Table 4: Table showing the different Data Stores

Data Store	Description
D1: Register	This stores details about the users of the application.
D2: Farm Input Inventory	This contains all the data about the different Farm Inputs from different clients and veterinarians.
D3: Farm Inputs Request File	This stores all Farm Input requests made by the Farmers.
D4: Contact Request File	This contains all the contacts and locations of the various clients and veterinarians.

Logical Database Design

The database schema is designed to be simple yet effective. It consists of several key tables managed by Supabase PostgreSQL. The diagram below shows the relationships between these tables.

Keys: PK - Primary Key, {FK} - Foreign Key

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Figure 6: Showing the Entity Relationship

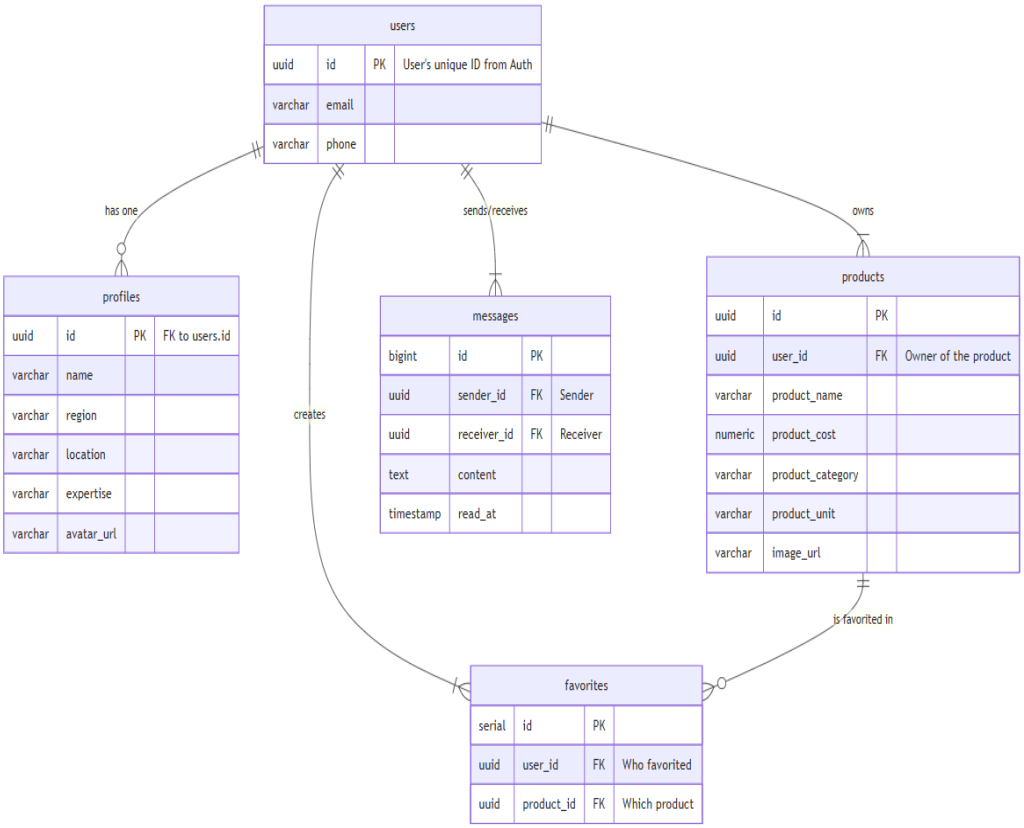

Table 5: users (managed by Supabase Auth)

This table stores user authentication information. Profile details are stored in a separate profiles table linked by the user's ID.

Field	Data Type	Null	Constraint	Description
Id	Uuid	Not Null	Primary Key	Unique identifier for each user
Email	Varchar	Nullable		User's email address
Phone	Varchar	Nullable		User's phone number
... (other auth fields)				

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Table 6: profiles

This table stores public-facing user profile data.

Field	Data Type	Null	Constraint	Description
Id	Uuid	Not Null	Primary Key, Foreign Key to auth. users.id	Links to the authentication user
Name	varchar(100)	Not Null		User's full name
Region	varchar(100)	Nullable		User's geographical region
location	varchar(100)	Nullable		More specific location details
expertise	varchar(100)	Nullable		User's area of expertise (e.g., Crops)
avatar_url	varchar	Nullable		URL to the user's profile picture
updated_at	timestamp	Nullable		When the profile was last updated

Table 7: products

Field	Data Type	Null	Constraint	Description
Id	Uuid	Not Null	Primary Key (auto-generated)	Unique identifier for the product
user_id	Uuid	Not Null	Foreign Key to auth. users.id	The user who owns the product
product_name	varchar(100)	Not Null		Name of the product
product_cost	Numeric	Not Null		Price of the product
product_category	varchar(100)	Nullable		Category (e.g., Vegetable, Fruit)
product_unit	varchar(50)	Nullable		Unit of sale (e.g., kg, bunch)
image_url	Varchar	Nullable		URL to the product image in Storage
created_at	timestamp	Not Null	Default now()	Timestamp of creation
updated_at	timestamp	Nullable		Timestamp of last update

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Table 8: messages

Field	Data Type	Null	Constraint	Description
Id	bigint	Not Null	Primary Key (auto-incrementing)	Unique identifier for the message
sender_id	Uuid	Not Null	Foreign Key to auth. users.id	The user who sent the message
receiver_id	Uuid	Not Null	Foreign Key to auth. users.id	The user who received the message
content	Text	Not Null		The text content of the message
read_at	timestamp	Nullable		Timestamp when the message was read
created_at	timestamp	Not Null	Default now()	Timestamp of creation

Table 9: favourites

	Data Type	Null	Constraint	Description
Id	Serial	Not Null	Primary Key	Unique identifier for the favourite entry
user_id	Uuid	Not Null	Foreign Key to auth. users.id	The user who favourited the item
product_id	Uuid	Not Null	Foreign Key to products.id	The product that was favourited
created at	Timestamp	Not Null	Default now()	Timestamp of creation

System implementation

This phase involved the development of the two main components of the hybrid system: the core Progressive Web App (PWA) and the native Android wrapper that houses it.

Technologies used to implement the application

The application was developed using a modern stack of web and mobile technologies:

Progressive Web App (Frontend):

HTML5: Provides the fundamental structure and content of the application's pages.

CSS3: Used for styling the application, ensuring a responsive and visually appealing layout.

Bootstrap 5: A popular CSS framework used to accelerate development and create a consistent, mobile-first user interface.

JavaScript (ES6 Modules): The primary language for all client-side logic, including routing, UI manipulation, user interactions, and communication with the backend.

Native Android Wrapper:

Java: The programming language used to build the native Android application shell.

Android SDK: Provides the tools and APIs necessary to create the Android application, including the WebView component.

XML: Used to define the layout of the native Android components, such as the WebView that displays the web application.

Backend (Backend-as-a-Service):

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Supabase: A comprehensive platform that provides all backend services for the application.
PostgreSQL Database: For storing all application data, including users, products, and messages.
Supabase Auth: For handling secure user registration, login, and session management.
Supabase Storage: For storing user-uploaded files, specifically product images.
Supabase Real-time: To power the live chat functionality by pushing updates to connected clients.

Data Interchange Format:

JSON (JavaScript Object Notation): Used as the standard format for transmitting data between the PWA and the Supabase backend.

Figure 7: Showing the login dashboard on the UnikAgric application.

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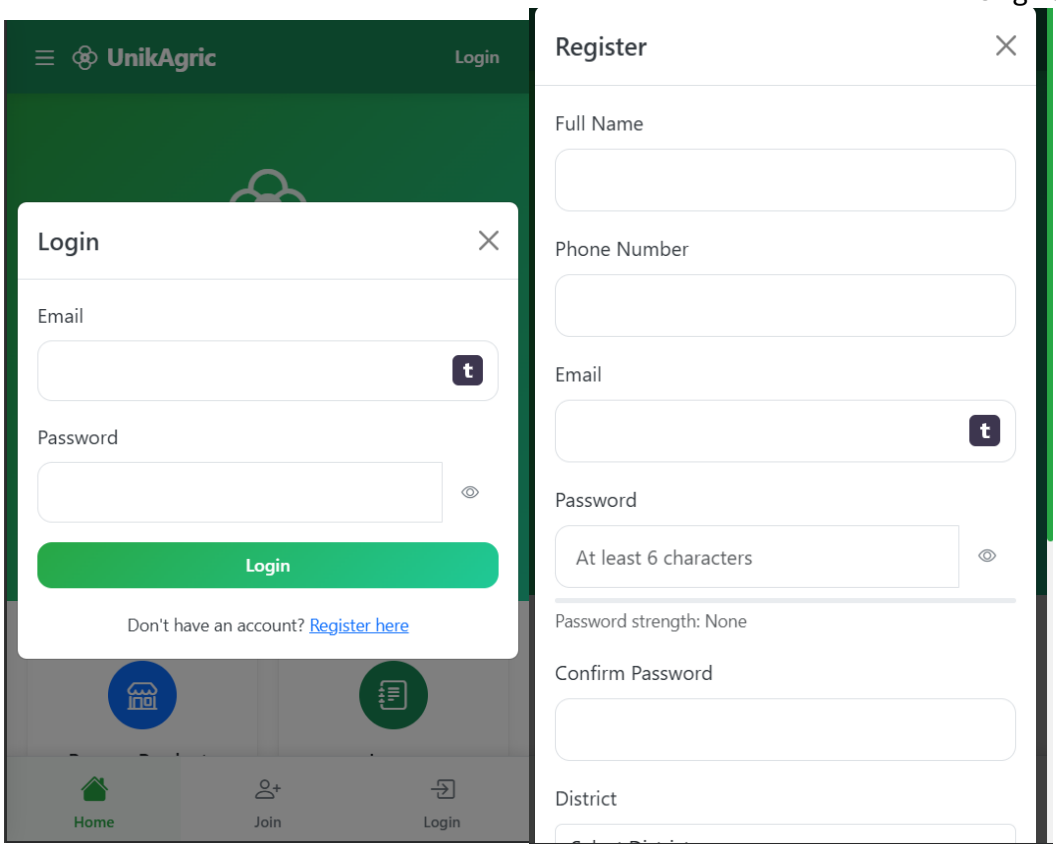

User Interface Implementation

The user interface is not built with native Android fragments but is rendered by the PWA using HTML, CSS, and JavaScript within the Android WebView. Below are descriptions of the key UI screens.

Home/Dashboard Screen: This is the main landing page for users. It displays a welcome message and features a grid of product categories and recently listed items. It includes top and bottom navigation bars for easy access to other parts of the application.

Product Details Screen: When a user selects a product, this screen appears, showing a larger image of the product, its price, description, and unit. It also displays information about the seller and provides a button to initiate a chat.

Messages and Chat Room Screen: The messages screen lists all ongoing conversations for the logged-in user, indicating unread messages. Tapping a conversation opens the chat room, which displays the message history and allows the user to send and receive messages in real-time.

Profile Management Screen: Here, users can view and update their personal information, such as their name, region, and area of expertise. Farmers can also view a list of the products they have posted for sale.

Authentication Modals: Instead of separate pages, login and registration forms appear in modals (pop-up windows) over the current screen, providing a seamless authentication experience without full-page reloads.

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Figure 8: Showing the user's dashboard on the UnikAgric application.

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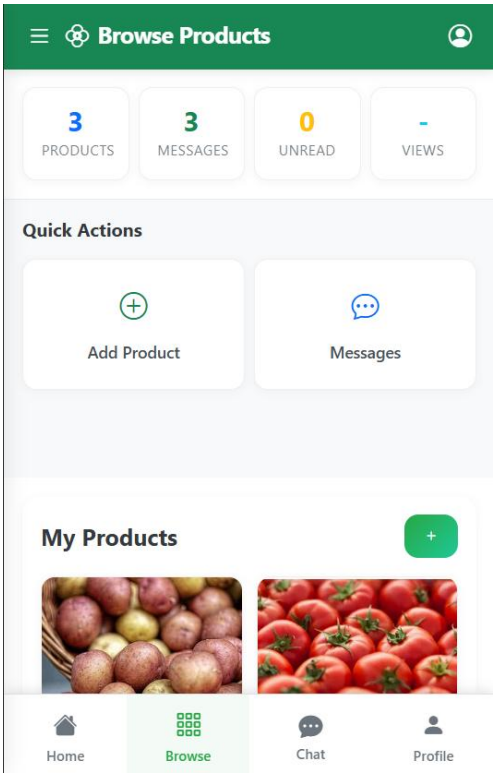

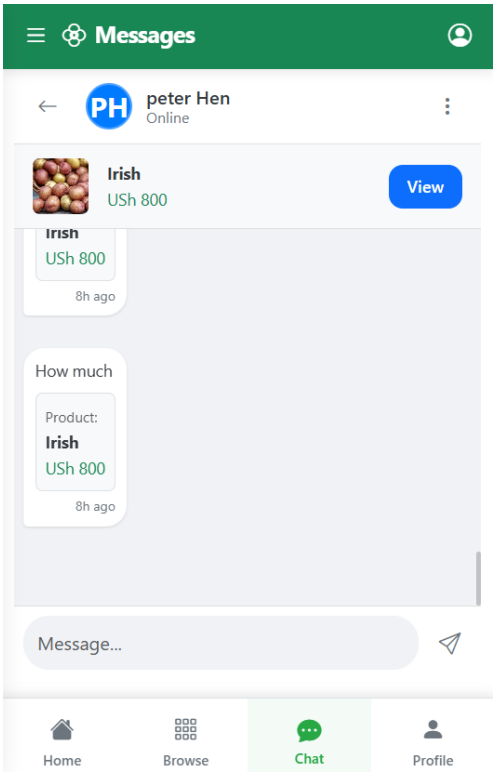

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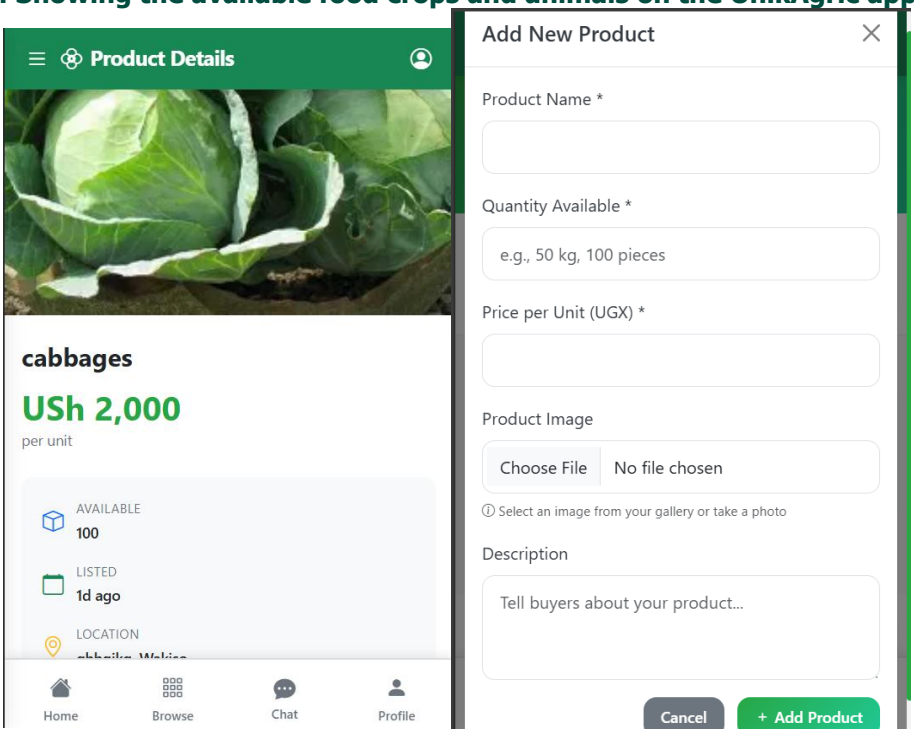
Fragment showing available food crops

Figure 9: Showing the available food crops and animals on the UnikAgric application.



System Testing

To ensure the application is reliable, functional, and meets user expectations, a multi-layered testing strategy was employed, covering both the web and native components.

Unit Testing

- **PWA:** Individual JavaScript modules (e.g auth.js, router.js) were tested in isolation to verify that their functions work correctly. For example, testing that the AuthManager correctly handles login and logout logic.
- **Android Wrapper:** The Java code in MainActivity.java was tested to ensure the WebView is configured correctly and that permissions for Camera and Storage are properly requested.

Integration Testing

This phase focused on testing the interaction between different parts of the system:

- **PWA to Supabase:** Verified that the PWA can successfully fetch data from the Supabase database, authenticate users, and upload files to storage.
- **PWA to Android Wrapper:** Tested the bridge between JavaScript and Java to ensure that actions in the web app (like clicking an "upload image" button) correctly trigger the native file chooser on the Android device.
- **Real-time Chat:** Two instances of the application were run to test the end-to-end flow of a message from a sender to a receiver, ensuring it appeared in real-time.

System Testing

The application was tested as a complete, integrated system from the user's perspective. This involved executing common user scenarios from start to finish:

Registering a new user account.
Logging in and updating a user profile.
Posting a new product with an image.
Searching for and viewing a product as another user.
Starting a chat and exchanging several messages.
Adding a product to favourites.
Logging out.

Acceptance Testing

A sample of target users (e.g., students, local farmers) was given the application to use. They were asked to perform tasks and provide feedback on its functionality, usability, and overall usefulness. This feedback was crucial for identifying any final issues and confirming that the system meets the real-world needs of its intended audience.

System Validation

The system was validated against the requirements defined in Chapter 4 to ensure it performs as designed.

- **Functional Validation:** Each functional requirement was checked. For example, it was confirmed that users can create accounts, post products, and chat in real-time, satisfying FR1, FR3, and FR4.
- **Usability Validation:** Users confirmed that the interface is intuitive and easy to navigate. The use of familiar icons and a standard mobile layout (bottom navigation) contributed to high usability.
- **Performance Validation:** The application's responsiveness was observed. Page loads and real-time message delivery were confirmed to be fast, providing a smooth user experience.
- **Security Validation:** It was verified that all communication with Supabase uses HTTPS, and that database policies prevent one user from accessing or modifying another user's private data.

Usefulness

Table 10: showing user satisfaction rate

Question	Answer	Percentage (%)
Having interacted with the application, how useful is it in assisting farmers with their clients?	Very useful	75
	Fairly useful	10
	Could be useful	10
	Not useful	5

Most of the respondents (75%) were positive that the “UnikAgric ” application was very useful since it connects farmers to their clients. However, those who were not in support of the system gave a common reason of it being expensive since it requires one to buy internet/data bundles.

Usability

This refers to the degree to which a system assists the people using it to accomplish a task. This was used to check whether the system interface is easy to navigate through.

Table 11: showing usability rate for the users.

Question	Answer	Percentage (%)
Do you find the interface easy to interact with?	Yes	80
	Fairly	15
	No	5

80% of the respondents found it very easy to navigate through the system. 15% found it fairly easy to navigate, and 5% of the respondents found it hard to navigate through the system.

Usage

Usage aimed at checking whether the provided guidelines of the newly developed system are clear.

Table 12: showing usage of the application.

Question	Answer	Percentage (%)
Were the guidelines helpful to you?	Yes	90
	No	10

90% of the respondents said that the guidelines were helpful to them and they were able to use the system. 10% of the respondents found the guidelines not helpful.

Discussion

Achievements

The project successfully met its primary objectives, resulting in a functional and modern digital marketplace for the agricultural community. Key achievements include:

- **Successful Hybrid Implementation:** A core achievement was the successful creation of a hybrid application. The Progressive Web App (PWA) provides a flexible, cross-platform base, while the native Android wrapper ensures a seamless experience for Android users, including access to device features like the camera and file system.
- **Real-time Communication:** The integration of Supabase's real-time capabilities to create a functional, live chat system was a major success. This feature is central to the application's goal of directly connecting buyers and sellers.
- **Modern Technology Stack:** The project was built using a modern, scalable, and maintainable technology stack (JavaScript ES6, Bootstrap 5, Supabase, Java). This provides a solid foundation for future development and maintenance.
- **Empowering Farmers:** The application provides a platform for farmers to bypass traditional intermediaries, potentially increasing their market reach and profitability.

Challenges Faced

Several challenges were encountered during the development process:

- **Integrating Web and Native Code:** Creating a reliable bridge between the JavaScript code in the PWA and the native Java code in the Android wrapper was complex. Ensuring that the file chooser and camera intents were triggered correctly from the WebView and that the results were passed back to the web app required careful implementation and testing.
- **Learning Curve with Supabase:** While powerful, effectively using all of Supabase's features, particularly setting up correct Row Level Security (RLS) policies for the database and managing real-time subscriptions, had a steep learning curve.
- **UI/UX for a Diverse Audience:** Designing an interface that is intuitive for users with varying levels of technical literacy was a significant challenge. The design had to be simple and clear without sacrificing essential functionality.
- **Testing a Hybrid System:** Testing the application was more complex than testing a purely web or native app. It required testing the PWA on its own in different browsers, testing the native Android wrapper, and, most importantly, testing the interaction between the two on multiple Android devices and versions.

Conclusion

The UnikAgric project successfully demonstrates the potential of modern web and mobile technologies to solve real-world problems in the agricultural sector. The application provides a viable platform that directly connects farmers and buyers, addressing the key weaknesses of traditional manual systems, such as limited access, high costs, and geographical constraints.

The choice of a hybrid architecture proved to be effective, allowing for rapid development of the core application using web technologies while still delivering a rich, near-native experience on Android. The resulting system is a functional, scalable, and user-friendly digital marketplace that fulfils all the primary objectives set out at the beginning of this project.

Recommendation

The study recommends wider adoption of the UnikAgric application to improve agricultural market integration among smallholder farmers in Uganda. To enhance its effectiveness and sustainability, future versions should incorporate secure mobile payment systems, improved search and filtering capabilities, user rating and review features, multilingual support, and enhanced offline functionality. The application should also be integrated with logistics and delivery services to facilitate the movement of agricultural products. Further research is recommended to assess the long-term impact of the system on farmers' income, market participation, and agricultural productivity, as well as explore advanced technologies such as machine learning for price prediction and expansion to other mobile platforms, including iOS.

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List of abbreviations

ICT	Information and Communication Technology
NAADS	National Agricultural Advisory Services
GDP	Gross Domestic Product
PMA	Plan for Modernisation of Agriculture
SMS	Short Message Service
GPS	Global Positioning System
ACACIA	African Connection and Community Access Initiatives for Africa
NGO	Non-Governmental Organization
DFD	Data Flow Diagram
UML	Unified Modelling Language
PHP	Hypertext Preprocessor
US$	United States Dollar
ILO	International Labour Organisation
UNIKAGRICAPP	University of Kisubi Agricultural Application

Data availability

Data is available upon request from the corresponding author.

Informed consent

Written informed consent was obtained from all participants before their inclusion in the study. Participants were informed about the purpose of the study, procedures involved, potential risks and benefits, and their right to withdraw at any time without penalty.

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Conflict of interest

The author did not declare any conflict of interest.

Author contributions

Eseza Nakayima was the principal investigator of this research project. She conceptualised the study, developed the proposal, collected and analysed the data, interpreted the findings, and prepared the final research report.
Aloyzious Ssenteza supervised the whole research process.

Author Biography

Eseza Nakayima is a student pursuing a Bachelor of Science degree in Computer Science in the Faculty of Business and ICT, University of Kisubi.
Aloyzious Ssenteza is a Lecturer in the Faculty of Business and ICT, University of Kisubi.

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