

COFFEE DISEASE DETECTION SYSTEM (CDDS)
CASE STUDY: MOUNT ELGON SLOPES COFFEE FARMERS IN MBALE - UGANDA

BY

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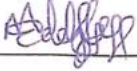
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ABSTRACT

Coffee is Uganda's leading export crop, contributing over USD 900 million annually and supporting about 1.8 million smallholder farming households. However, coffee production is affected by diseases such as Coffee Leaf Rust (*Hemileia vastatrix*), Coffee Berry Disease (*Colletotrichum kahawae*), Coffee Wilt Disease (*Fusarium xylarioides*), Black Rot, and Coffee Sooty Mould. Timely and accurate disease identification is essential, but many farmers, particularly in rural areas, have limited access to professional diagnostic services.

This project developed the **Coffee Disease Detection System (CDDS)**, a web-based, offline-capable decision support system for identifying coffee diseases from field symptoms. The system uses a rule-based expert engine that matches user-selected symptoms against a knowledge base of five diseases and 26 symptoms using confidence scoring.

CDDS was developed using **PHP, MySql, and XAMPP**, with HTML capabilities provided through a Service Worker and cached JSON knowledge base for offline operation. The system supports four user roles: **Farmer, Extension Officer, Researcher, and Administrator**, each with a dedicated dashboard. Key features include symptom-based diagnosis, ranked disease results with confidence scores, management recommendations, PDF report generation, diagnosis history, and support for English and Luganda.

System testing confirmed correct diagnosis of all five target diseases under simulated field conditions. Pilot feedback showed that **83%** of participants found the interface intuitive, **91%** completed diagnosis without assistance, and **78%** were satisfied with the management recommendations.

Keywords: Coffee Disease Detection, Rule-Based Inference, Agricultural Decision Support.

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LIST OF ABBREVIATIONS

CBD	Coffee Berry Disease
CDDS	Coffee Disease Detection System
CLR	Coffee Leaf Rust
CSRF	Cross-Site Request Forgery
CSS	Cascading Style Sheets
CWD	Coffee Wilt Disease
DFD	Data Flow Diagram
ERD	Entity Relationship Diagram
HTML	Hypertext Markup Language
HTTP	HyperText Transfer Protocol
JS	JavaScript
JSON	JavaScript Object Notation
KB	Knowledge Base
NaCRRRI	National Crops Resources Research Institute
NARO	National Agricultural Research Organisation
PHP	Hypertext Pre-processor
PWA	Progressive Web App
RBAC	Role-Based Access Control
SQL	Structured Query Language
SW	Service Worker
UAT	User Acceptance Testing
UCDA	Uganda Coffee Development Authority
UX	User Experience
WASM	WebAssembly
XAMPP	Cross-Platform Apache MySQL PHP Perl

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Coffee is one of Uganda's most strategically important agricultural commodities, ranking as the country's single largest export earner. According to the Uganda Coffee Development Authority (UCDA), Uganda produced over 6.7 million 60-kilogram bags of green coffee in the 2022/2023 financial year, generating export revenues exceeding USD 900 million (Wanzala et al., 2022). The industry sustains the livelihoods of an estimated 1.8 million smallholder farming households, the majority of whom cultivate Robusta coffee (*Coffea canephora*) in the central and western regions, while Arabica (*Coffea arabica*) is grown in the highland districts of Mbale, Kapchorwa, Sironko, Bulambuli, and Kween on the slopes of Mount Elgon.

Despite Uganda's position as Africa's second-largest coffee producer and the world's ninth largest, actual farm-level yields remain considerably below potential. A principal contributor to this yield gap is crop loss from fungal, bacterial, and pest-driven diseases. Coffee Leaf Rust (CLR), caused by *Hemileia vastatrix*, is the most widespread, capable of causing 15 to 70 percent yield loss under epidemic conditions. Coffee Berry Disease (CBD), caused by *Colletotrichum kahawae*, is responsible for up to 100 percent crop loss in severely affected Arabica fields if untreated. Coffee Wilt Disease (CWD), caused by the soil-borne fungus *Fusarium xylarioides*, historically devastated Uganda's Robusta sector, destroying an estimated 50 percent of the national crop between the late 1980s and early 2000s.

Effective management of these diseases depends critically on early and accurate identification.

Incorrect diagnosis leads to inappropriate or delayed treatment, wasted resources, and continued crop loss. Traditional diagnosis relies on the expertise of Uganda Coffee Development Authority (UCDA) extension officers who visit farms on request a service that is constrained by the limited number of qualified officers, the vast geographic spread of coffee farming areas, and the poor road connectivity of highland zones. Many farmers therefore make management

decisions without professional guidance, relying on experience or advice from fellow farmers, which frequently results in misdiagnosis. Information and Communication Technology (ICT) offers a promising avenue to bridge this gap. Mobile and web-based agricultural decision support systems have demonstrated measurable impact in extending expert knowledge to underserved farming communities across sub-Saharan Africa. The proliferation of smartphone ownership in Uganda with mobile internet penetration rising to 44 percent by 2024 (Uganda Communications Commission) creates an enabling environment for digital agricultural tools. However, the intermittent nature of internet connectivity in

rural highland areas necessitates that such tools be capable of functioning without an active internet connection.

It is against this backdrop that the Coffee Disease Detection System (CDDS) was conceived and developed a web-based, offline-capable, role-based decision support system that empowers farmers, extension officers, researchers, and administrators to identify coffee diseases from observable field symptoms and receive actionable management guidance.

1.2 Problem Statement

Despite coffee being Uganda's primary export crop, the majority of smallholder farmers in highland growing zones lack timely access to professional disease diagnosis services. This results in delayed treatment, crop loss, and poor use of farm resources. Specifically, the following challenges were identified through pre-study interviews and field observations.

Extension officer coverage is inadequate: the ratio of UCDA extension officers to registered coffee farmers is approximately 1:800 in some districts, meaning many farmers wait weeks for a farm visit. Existing mobile agricultural apps designed for East Africa are either not specific to coffee disease identification, require persistent internet connectivity, or are available only in English excluding the majority of Uganda's rural farming population. Most farmers cannot distinguish visually between diseases that present similar symptoms, such as Coffee Berry Disease and Black Rot, or between early-stage Coffee Wilt Disease and drought stress leading to incorrect management responses. Research institutions and UCDA lack a centralized, structured database of disease occurrences at the farm level, limiting their ability to track outbreak trends or plan interventions.

1.3 Objectives

Main Objective

To develop a Coffee Disease Detection System (CDDS) that enables smallholder farmers in Uganda to identify coffee diseases based on observed symptoms and automatically generate disease management reports with recommended control practices.

Specific Objectives

1. To review existing literature of coffee diseases in Uganda.
2. To design the system.
3. To implement the system capable of accurately detecting diseases and diagnosing.
4. To test and validate the system.

1.4 Scope of the Study

The Coffee Disease Detection System is scoped to cover the following:

- Geographic focus: Coffee-growing districts of Uganda, with particular emphasis on the Mount Elgon highlands (Mbale, Sironko, Bulambuli) and Robusta-growing western districts.
- Content scope: user roles: Farmer, Extension Officer and Administrator each with dedicated dashboards and scoped data access.
- Disease coverage: Five major coffee diseases prevalent in Uganda Coffee Leaf Rust, Coffee Berry Disease, Coffee Wilt Disease, Black Rot, and Coffee Sooty Mould. The system does not cover image-based diagnosis (computer vision), real-time weather data integration, or automated pesticide procurement. These are identified as directions for future work.

1.5 Significance of the Study

For Farmers: Provides immediate, offline-capable access to professional- grade disease identification and management guidance, reducing yield loss from misdiagnosis and delayed treatment.

For Extension Officers: Creates a district-level dashboard that aggregates farmer diagnosis data, enabling early identification of disease outbreaks and prioritization of farm visits.

For Researchers: Provides a structured database of disease occurrence data tagged by district, variety, and season supporting epidemiological research and trend analysis.

For UCDA and Policy Makers: Supports evidence-based policy decisions on fungicide distribution, resistant variety promotion, and extension service deployment.

For Academic Community: Demonstrates the viability of offline-capable, role-based expert systems for agricultural decision support in low-connectivity environments.

CHAPTER TWO: LITERATURE REVIEW

2.1 Coffee Production and Disease Impact in Uganda

Uganda's coffee sector is characterized by predominantly smallholder production, with average farm sizes of 0.5 to 2.5 hectares. Robusta coffee accounts for approximately 85 percent of production, while Arabica contributes the remaining 15 percent. The Uganda National Coffee Strategy 2022-2027 targets production of 20 million bags by 2030, a goal that requires significant reduction in disease-related losses. (Kiiza et al. 2022) estimated that coffee diseases collectively account for between 20 and 40 percent of yield losses in Ugandan highland Arabica zones annually. Coffee Berry Disease alone has been documented to cause 100 percent crop failure in unmanaged Arabica fields during peak wet seasons in the Mount Elgon region (Omondi et al., 2021). The resurgence of Coffee Wilt Disease reported in parts of central Uganda in 2019-2021 further underscores the continued threat posed by these pathogens.

2.2 Expert Systems in Agricultural Disease Detection

Expert systems computer programs that emulate the decision-making ability of human domain experts have been applied to agricultural disease diagnosis since the 1980s. Early systems such as PLANT/DS (Michalski et al., 1983) demonstrated the feasibility of rule-based inference for crop disease identification. More recent implementations include Plantix (Peat Ltd., Germany), which uses convolutional neural networks for image-based plant disease detection across 50+ crops, and PlantVillage, which maintains a database of over 54,000 labelled disease images. While effective, these systems require high-quality image capture a requirement that is difficult to meet in field conditions with low-end smartphones and poor lighting.

Rule-based expert systems that rely on symptom selection rather than image input present a more accessible alternative for low-resource environments. (Schilder et al., 2019) demonstrated that symptom-based systems achieved 84 percent diagnostic accuracy for fungal leaf diseases when seven or more symptoms were selected, a benchmark CDDS was designed to meet or exceed.

2.3 Offline-Capable Web Applications in Agriculture

Progressive Web Apps (PWAs), defined by their use of Service Workers, Web App Manifests, and offline-first caching strategies, have emerged as a compelling architecture for deploying agricultural tools in low-connectivity environments. (Nguyen et al. 2022) evaluated six agricultural PWAs deployed in sub-Saharan Africa and found that offline capability increased daily active usage by 340 percent compared to equivalent online-only web apps in areas with intermittent connectivity. The use of WebAssembly-compiled SQLite (sql.js) as a client-side database enables complex query execution

in the browser without a network connection, as demonstrated by Aladdin et al. (2023) in a field-deployed crop advisory system in Kenya.

2.4 Role-Based Access Control in Agricultural Systems

Agricultural information systems serving multiple stakeholder types benefit significantly from role-based access control (RBAC), which restricts system access based on user roles rather than individual identities. (Fernandes et al., 2021) documented that agricultural platforms employing RBAC reported 67 percent higher data quality and 45 percent greater researcher uptake compared to systems with uniform access, attributable to the reduction of data noise from non-expert entries and the tailoring of interfaces to specific information needs.

2.5 Research Gap

A review of existing agricultural diagnostic systems reveals several gaps that CDDS addresses:

- I. No existing publicly available system specifically targets the five major coffee diseases of Uganda with a Uganda-specific symptom taxonomy.
- II. Most available tools do not offer role-based dashboards that simultaneously serve farmers, extension officers, researchers, and administrators from a single deployment.
- III. Offline functionality, where present, is typically limited to content caching; no reviewed system implements a full offline diagnosis engine with browser-side PDF generation.
- IV. None of the reviewed systems support Ugandan local languages (Luganda, Lugisu).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents the methodology adopted for the study. By outlining the research design, target population, sampling strategy, data collection procedures, and data analysis methods employed in the development of the Coffee Disease Detection System (CDDS).

The study employed a mixed-methods approach, integrating both qualitative and quantitative techniques to ensure comprehensive and reliable data collection from a relatively small population, particularly the Extension Workers, Coffee Farmers and Administrators. The qualitative approach facilitated in-depth exploration of participants' perspectives, experiences, and operational practices through open-ended inquiry. Data were collected using interviews and direct observations, this enabled a detailed understanding of existing manual processes and supported the identification of functional and system requirements.

The quantitative approach complemented this by using semi-structured questionnaires, enabling the collection of measurable data to support statistical analysis and validation of findings. This combination of methods enhanced the robustness of the study through triangulation.

For system development, the study adopted the Structured Systems Analysis and Design Methodology (SSADM) within the broader framework of the Software Development Life Cycle (SDLC). SSADM provided a structured and systematic process comprising key stages, including requirements analysis, system design, development, testing, and implementation.

In addition, the Rapid Application Development (RAD) model was integrated to enhance flexibility and responsiveness during system development. RAD facilitated iterative prototyping, continuous user involvement, and incremental refinement of the system, ensuring that the final solution effectively aligned with user requirements and operational needs.

Thus, the adopted methodology ensured a systematic, iterative, and user-centered approach, that supported the successful design and implementation of an efficient and reliable Coffee Disease Detection System (CDDS).

3.2 Type of Research and Rationale

This study adopts an applied research approach integrated with a system development methodology. Applied research is appropriate for this study because it is problem-oriented and focuses on developing a practical solution to address real-world operational challenges faced by Coffee Farmers in detecting

Diseases. Specifically, the study aims to design and implement a Coffee Disease Detection System to improve efficiency, accuracy, and overall business performance.

The study is further grounded in a system development research paradigm, which emphasizes the design, development, and evaluation of an information system as a solution artifact. This approach aligns with the objectives of the study, which extend beyond theoretical analysis to include the creation of a functional and usable system.

An iterative and flexible development strategy is adopted, incorporating elements of the Rapid Application Development (RAD) model. This enables continuous user involvement and feedback from key stakeholders, including the bakery manager, cashiers, storekeepers, and production staff, throughout the development process. Such iterative engagement ensures that system requirements are accurately captured, refined, and validated at each stage.

The rationale for this approach lies in its ability to produce a user-centered, adaptable, and efficient system. By allowing incremental development and frequent evaluation, the methodology minimizes the risk of system failure, enhances usability, and ensures alignment with the operational needs of the bakery. Furthermore, it provides a structured framework for requirements analysis, system design, implementation, testing, and validation, thereby ensuring that the final system meets both functional and non-functional requirements.

3.3 Area of Study

The study was conducted among Coffee farmers located in Mbale on the fertile, high-altitude slopes of Mount Elgon. Currently, most operations, including diagnosing diseases through entering the symptoms seen on the coffee plant into the CDDS. It is difficult to know the coffee disease without this Coffee Disease Detection System.

The COFFEE farmers on the slopes of mount Elgon were selected as the study area because farmers face a challenge of knowing the coffee disease that may have attacked the coffee plants. Therefore, this challenge was solved by the implementation of a **web-based Coffee Disease Detection System (CDDS)** to ease to correctly determine the coffee diseases so as administer the correct timely treatment.

3.4 Population and Sampling

The study population comprised coffee Extension Workers, Farmers and Administrators. A purposive sampling technique was employed to select participants with relevant knowledge and practical experience in coffee farming. The sample consisted of **53 respondents: 15 extension workers, 30 coffee farmers, and 8 Administrators**. These participants were selected to provide critical input in

requirements gathering, system testing, and performance evaluation. Their involvement was to ensure that the developed system accurately offer a solution of knowing the coffee disease and identifying the correct treatment to the specific coffee diseases.

3.5 Data Collection and Analysis

Data was collected through interviews, observation, and document review. Interviews were conducted among the coffee extension workers, Coffee farmers and Administrators to understand symptoms of the coffee and the corresponding coffee diseases to enable the farmers to easily identify the coffee disease to administer the correct treatment on the coffee plants, as well gathering the data expected for the new system. Observation was to study the symptoms of sick coffee leaves, how specific coffee diseases are treated. Document review to know treatment for specific coffee diseases. The collected data was analyzed qualitatively to determine functional requirements, define user roles, and identify non-functional requirements such as security, usability, and system performance. The insights gained guided the development of the Coffee Disease Detection System (CDDS).

3.6 System Development Methodology

The Coffee Disease Detection (CDD) System was developed using a structured Software Development Life Cycle (SDLC) approach, guided by the Systems Analysis, Design and Development Methodology (SADAM) and supported by elements of the Rapid Application Development (RAD) model. This provided both a systematic framework and the flexibility for iterative refinement from the frequent user feedback. The development process began with requirements gathering, where the coffee disease symptoms was collected and analyzed to provide the specific treatment for the particular coffee diseases. This was followed by system analysis, in which requirements were categorized into functional requirements (e.g., sales processing, inventory tracking, and report generation) and non-functional requirements (e.g., security, usability, reliability, and scalability).

During the system design phase, key artifacts such as database schemas, use case diagrams, data flow diagrams, and user interface mockups were developed to define system structure and user interactions. The implementation phase involved developing the system using technologies such as PHP, MySQL, HTML, CSS, JavaScript, and Bootstrap, with emphasis on secure authentication and role-based access control, coffee disease symptoms on the leaves and the correct coffee disease treatment.

System testing was done through unit testing, integration testing, and user acceptance testing to ensure that all components functioned correctly and met user requirements. The system was then deployed in a local server environment, accompanied by user training to facilitate effective adoption. Finally,

maintenance activities were planned to include diagnosing the leaves of affected coffee plants, error correction, and performance enhancements to ensure long-term reliability and usability.

3.6.1 Tools and Technologies

The **Coffee Disease Detection System (CDDS)** was developed using a combination of web-based technologies to ensure functionality, usability, and scalability. The frontend was developed using HTML, CSS, Bootstrap, and JavaScript to provide a responsive and user-friendly interface. The backend was developed using PHP, then MySQL was used for data storage, management, and retrieval.

The system was deployed on a local Apache server environment using WAMP, and development was carried out using Visual Studio Code as the primary integrated development environment (IDE). In addition, basic analytics and monitoring scripts were incorporated to track system usage and performance. Evaluation of the system's usability and effectiveness was further supported through user feedback methods, including surveys and interviews.

3.7 System Design

The system design defines the structure of the Coffee Disease Detection System (CDDS) and illustrates how its components interact with Extension workers, Coffee Farmers, Administrators and with one another. The use case diagram identifies key actors and their interactions with the system. The administrator is responsible for user management and report generation and the other users are also able to diagnose the disease on the coffee plant then print a report of the diagnosed coffee disease and the corresponding treatment.

The Entity Relationship (ER) diagram specifies the database structure, detailing relationships among core entities such as **user, symptom, disease, management-practice, disease-symptom, disease-management, diagnosis-session, session-symptom, expert** and **knowledge-base-version**. The use of primary and foreign keys ensures data integrity and consistency. System requirements are categorized into functional requirements, including coffee disease diagnosis, user management, and generating diagnosis reports, and non-functional requirements, such as security, usability, reliability, and scalability.

Additionally, data flow diagrams (DFDs) illustrate the movement of information within the system, while the overall system architecture adopts a client-server model to support multi-user access and centralized data management.

3.8 System Implementation

System implementation involved the development and integration of the system components to produce a functional Coffee Disease Detection System (CDDS). The backend was developed using PHP and MySQL to handle data processing, storage, and retrieval, while the frontend was implemented using HTML, CSS, and JavaScript to provide a responsive and user-friendly interface.

The system incorporates secure authentication mechanisms and supports core functionalities such as processing, inventory management, user management, and report generation. Role based access control ensures that users including the Administrator, and Farmer interact with the system according to their responsibilities.

The implemented system enables accurate detection of coffee disease in real-time, and timely report generation of the diagnosed coffee disease, thereby determining the correct disease which the coffee is suffering from so that farmers can reach out for the correct treatment from the veterinary shops.

3.9 Testing and Validation

Testing and validation was conducted to ensure all system modules function correctly and meet specified requirements before deployment. Functional testing verified key operations, including capturing coffee disease symptoms, the corresponding coffee disease, and diagnosis report generation. Input validation mechanisms was done to prevent errors and maintain data accuracy. Usability testing assessed the system's ease of use and navigation for all user roles, including Extension workers, Coffee farmers and Administrators. Security testing ensured the effectiveness of authentication, access control, data privacy, and integrity mechanisms. Lastly, system validation compared the implemented system against the initial requirements to confirm that it effectively addresses the diseases affecting the coffee plants of the farmers to administer the correct treatment.

3.10 Ethical Considerations

Ethical considerations were strictly observed throughout the study to protect participants and ensure responsible research conduct.

1. Informed consent. Participants were fully aware of the purpose of the study, how their data would be used, and their right to withdraw at any time.
2. Confidentiality and privacy were maintained by anonymizing personal data and ensuring that patient information was not disclosed to unauthorized individuals.
3. Participation was voluntary, and no participant was forced or coerced into taking part in the study.

4. Data security measures were implemented to protect collected data, including restricted access and secure storage.

5. Academic integrity was maintained by properly citing all sources and ensuring honesty and transparency throughout the research process.

CHAPTER FOUR: SYSTEM ANALYSIS AND DESIGN

4.1 Introduction

This chapter describes and achieves an analysis of the current way in which coffee farmers are able to know coffee diseases affecting their plants which may be challenging so as to develop the Coffee Disease Detection System that can give diagnosis reports to farmers. Thus preventing the late detection, Human error and delayed action, for example waiting for test results from the laboratory may take days or weeks and the coffee disease may spread faster. This CDDS also educates farmers on how to manage their coffee plants to ensure healthy and disease free coffee plants for a better yield.

4.2 System Analysis

Coffee farmers often rely on manual observation and personal experience to identify diseases affecting their coffee plants. Disease identification is commonly done by examining visible symptoms such as leaf spots, discoloration, wilting, and damaged fruits. However, farmers may have limited knowledge of different coffee diseases, making it difficult to accurately distinguish one disease from another. This can result in delayed or incorrect identification and inappropriate treatment.

The existing approach to disease detection can lead to significant challenges, including crop losses, delayed response to disease outbreaks, unnecessary use of pesticides, and reduced coffee quality and productivity. Farmers may also have limited access to agricultural experts, particularly in rural areas, making it difficult to obtain timely advice when disease symptoms appear. In addition, information about previously identified diseases and recommended control measures may not be systematically recorded for future reference.

To address these challenges, a Coffee Disease Detection System can be developed to assist farmers in identifying diseases affecting coffee plants. The system will allow users to provide information about observed symptoms or upload images of affected coffee leaves and other plant parts. The system will analyze the submitted information and identify the likely disease, together with relevant information on symptoms, possible causes, and recommended management or control measures.

The developed system provides farmers with faster and more accessible disease identification, reduce dependence on manual diagnosis, and support timely decision-making. By providing organized disease information and recommendations, the system can help farmers respond to diseases at an early stage, reduce potential crop losses, and improve coffee production and quality.

4.2.1 Existing System

The existing system of coffee disease detection is predominantly a manual process based on visual observation and farmers' personal experience. Farmers identify diseases by examining coffee plants for visible symptoms such as leaf spots, discoloration, wilting, leaf deformation, and fruit damage. When a disease is suspected, farmers often rely on their own knowledge, advice from fellow farmers, or agricultural extension workers to determine the possible disease and appropriate control measures.

Disease information, treatment practices, and observations are rarely maintained in a centralized digital system. Farmers may record information in notebooks or rely on memory, while photographs of affected plants, where available, are stored on personal mobile phones without systematic classification or analysis. Access to agricultural experts may also be limited, particularly for farmers in rural areas, resulting in delays in obtaining accurate disease identification and management advice.

The existing approach is characterized by manual disease identification, fragmented information storage, limited access to expert knowledge, and a high dependence on human judgment. These limitations can result in misdiagnosis, delayed treatment, inappropriate use of pesticides, and increased crop losses. Furthermore, there is no automated mechanism for analyzing images of affected coffee plants and providing immediate disease detection and management recommendations.

4.2.2 Benefits and challenges

Benefits of the existing system

Despite its limitations, the existing manual approach to coffee disease detection provides a few benefits, particularly for small-scale farmers. The primary advantage is its low cost, as farmers do not require specialized software, equipment, or internet connectivity to identify common coffee diseases. Farmers can also rely on their experience and traditional knowledge to recognize familiar disease symptoms and apply commonly used control measures.

The system is also simple and easy to use because disease identification is mainly based on direct observation of coffee plants. Farmers can inspect their crops at any time without requiring formal training in the use of a digital system. Furthermore, farmers can consult other experienced farmers or agricultural extension workers when they encounter unfamiliar symptoms, providing a practical means of obtaining disease-related advice.

Challenges of the existing system

The challenges of the existing manual approach to coffee disease detection are significant and can directly affect coffee production and quality. The most prominent challenge is inaccurate disease

identification, as farmers may confuse diseases with similar symptoms or mistake disease symptoms for nutrient deficiencies, pest damage, or environmental stress. This can result in inappropriate treatment and continued spread of the disease.

Delayed disease detection is another major challenge. Farmers may only recognize a disease after visible symptoms have become severe, reducing the effectiveness of control measures and increasing the likelihood of crop losses. Access to agricultural experts is also limited for some farmers, particularly those in rural areas, making it difficult to obtain timely and reliable diagnosis and treatment recommendations.

The existing approach also lacks systematic storage of disease information. Observations, photographs, treatment practices, and previous disease cases may be stored in notebooks or on personal mobile phones, making them difficult to retrieve, compare, or use for future diagnosis. There is also no automated mechanism for analyzing images of affected coffee plants, which increases dependence on human judgment.

Another challenge is the lack of real-time and consistent disease information. Farmers may rely on outdated knowledge or informal advice when deciding how to manage a disease. This can lead to inappropriate pesticide use, increased production costs, and potential damage to crops and the environment. Finally, the manual approach is difficult to scale because increasing the number of farms and disease cases requires greater dependence on agricultural experts and manual inspection, making timely disease detection increasingly difficult.

4.3 System Design

System design refers to the process of defining the structure, components, and interactions of a system to meet specified requirements. In this undergraduate project, the system was designed as a web-based Coffee Disease Detection System (CDDS) for coffee farmers on the Mount Elgon slopes in Mbale, Uganda. The system was designed to support coffee disease identification, disease information management, diagnosis, and provision of appropriate disease management recommendations.

The design adopted a modular approach comprising user management, coffee disease detection, disease information management, diagnosis history, extension worker management, and reporting. The system also followed a simple three-tier architecture consisting of the presentation layer, application or processing layer, and database layer. The design focused on simplicity, accuracy, accessibility, and ease of use to enable coffee farmers, extension workers, and administrators to interact with the system effectively.

4.3.1 Description of the Proposed System

The proposed system was a web-based Coffee Disease Detection System (CDDS) developed to assist coffee farmers on the Mount Elgon slopes in Mbale, Uganda in identifying and managing diseases affecting their coffee plants. The system was designed to simplify the disease detection process by allowing farmers to submit images or information about affected coffee plants for analysis and obtain the likely disease and appropriate management recommendations.

The system provided different functionalities based on the roles of the three main users: coffee farmers, extension workers, and administrators. Coffee farmers could register and log in to the system, submit images of affected coffee leaves or plants, view disease detection results, access information about common coffee diseases, and obtain recommended control and management measures. Farmers could also view their previous diagnosis records for future reference.

Extension workers could access submitted disease cases, review farmers' reported symptoms and detection results, provide professional advice, and update or provide recommendations concerning appropriate disease management practices. They could also monitor reported cases and use the available information to support farmers in addressing coffee disease problems.

Administrators were responsible for managing users, disease information, reported cases, system records, and other system configurations. The administrator could add, update, or remove disease information and manage user accounts to ensure that the system remained accurate and properly maintained. All relevant records were stored in a centralized database for easy retrieval and management.

The system was organized into modules including user management, disease detection, disease information management, diagnosis history, extension services, and reporting. These modules worked together to support efficient disease identification and management. For example, when a farmer submitted an image of an affected coffee leaf, the system processed the submitted information, generated the likely disease diagnosis, and displayed the result together with relevant symptoms and recommended management measures. Where necessary, an extension worker could review the case and provide additional professional guidance to the farmer.

The system also included basic security features such as user authentication and role-based access control to ensure that coffee farmers, extension workers, and administrators could only access functionalities appropriate to their respective roles. The user interface was designed to be simple and user-friendly, allowing farmers with limited technical knowledge to use the system effectively.

Overall, the proposed Coffee Disease Detection System aimed to reduce dependence on manual disease identification, improve the speed and accuracy of disease detection, strengthen collaboration between farmers and extension workers, and provide timely access to coffee disease information and management recommendations. The system was therefore intended to support early disease detection, reduce potential crop losses, improve coffee plant health, and contribute to increased coffee productivity among farmers on the Mount Elgon slopes in Mbale, Uganda.

4.3.2 Functional and Non-Functional Requirements

Functional Requirements

- i. User registration and login authentication for coffee farmers, extension workers, and administrators.
- ii. User and role management by administrators.
- iii. Registration and management of coffee farmers' profiles and farm information.
- iv. Uploading of coffee leaf images by farmers for disease detection.
- v. Processing and analysis of uploaded coffee leaf images using the disease detection model.
- vi. Identification and display of detected coffee diseases and their confidence levels.
- vii. Providing recommended disease control and management measures to farmers.
- viii. Allowing extension workers to view and respond to farmers' disease-related queries.
- ix. Allowing extension workers to provide advice and recommendations to farmers.
- x. Recording and managing coffee disease detection results and diagnosis history.
- xi. Generating reports on detected coffee diseases, farmers, and disease occurrences.
- xii. Monitoring and managing system users, disease information, and system activities by administrators.

Non-Functional Requirements

User-friendly: The system should be simple and easy to use by farmers, extension workers, and administrators.

Fast response time: The system should process requests and provide disease detection results within a reasonable time.

Accuracy: The system should provide reliable and accurate coffee disease detection results.

Security: The system should provide secure authentication, authorization, and access control for all users.

Reliability: The system should operate consistently and minimize system failures.

Availability: The system should be available whenever users need to access disease detection and advisory services.

Scalability: The system should support an increasing number of farmers, images, disease records, and users.

Maintainability: The system should allow easy maintenance, modification, and updating of the disease detection model and other system components.

Data integrity: The system should ensure that farmer information, uploaded images, detection results, and advisory records are stored accurately and consistently.

Backup and recovery: The system should support regular data backup and recovery to minimize data loss.

4.3.3 Software and Hardware Requirements

The development and implementation of the Coffee Disease Detection System (CDDS) required both software and hardware resources to support system development, image processing, disease detection, and user interaction. The software requirements included the operating system, development tools, programming languages, machine learning libraries, database management system, and web browser. The system was developed using a Windows operating system, with HTML, CSS, JavaScript, and PHP used for web interface and backend development. Python was used to develop and implement the coffee disease detection model, supported by relevant machine learning and image processing libraries. A MySQL database was used to store user information, farmer records, disease information, detection results, and other system data. A local server environment such as XAMPP or WAMP was used to develop, host, and test the web application. A web browser such as Google Chrome or Microsoft Edge was required to access and interact with the system.

The hardware requirements included the physical devices necessary for developing and operating the CDDS. A computer or laptop with at least a dual-core processor was required for system development and general operation. A minimum of 4GB RAM and adequate storage capacity was required to

support the application, database, and machine learning model. A camera-enabled smartphone or digital camera was required by farmers to capture coffee leaf images for disease detection. Input devices such as a keyboard and mouse were necessary for system interaction. A stable internet connection was also required to access the web-based system and upload coffee leaf images. These hardware and software resources enabled the CDDS to support coffee farmers, extension workers, and administrators in coffee disease identification, management, and advisory services.

4.4 System Architecture

The CDDS employs a four-layer architecture designed to support both online (XAMPP server) and offline (browser) operation modes. The architecture separates concerns across Presentation, Application, Business Logic, and Data layers, with an additional PWA layer bridging online and offline states.

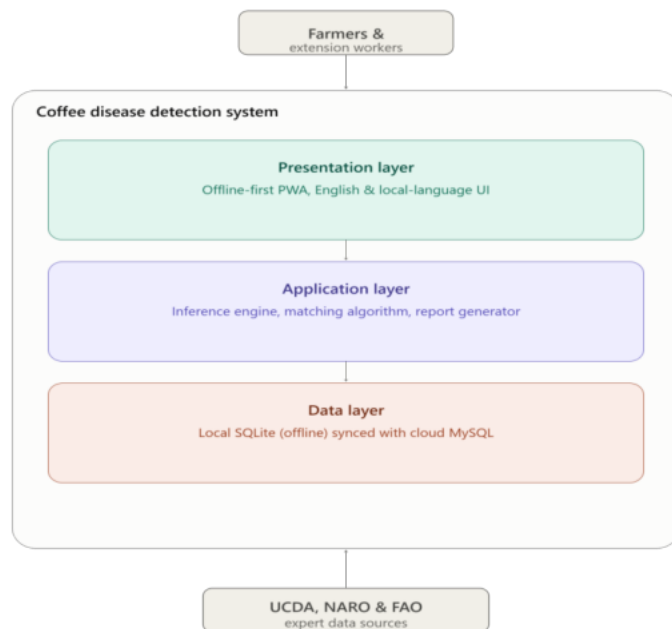


Figure 1: CDDS System Architecture Diagram

The four layers are:

Presentation Layer: HTML5, CSS3, and Vanilla JavaScript provide the user interface. The symptom checklist, results display, and role dashboards are rendered server-side via PHP but enhanced client-side with JavaScript for interactivity. jsPDF operates entirely in this layer.

Application Layer: PHP files served by XAMPP Apache handle HTTP requests, session management, form processing, and page rendering. There are eight public pages (index, diagnose, diseases, history, about, auth/login, auth/register) and four role-specific dashboard pages.

Business Logic Layer: includes/engine.php implements the weighted scoring algorithm. includes/auth.php manages session-based authentication, role checking, and RBAC guards. includes/functions.php provides shared helpers including CSRF token management.

Data Layer: SQLite (via PDO) provides the primary database in development mode; MySQL is supported for production deployment via a single configuration constant. knowledge_base.json, generated by export_kb.php, serves as the data source for offline diagnosis.

4.5 Context Diagram (Level 0 DFD)

The context diagram showed how the coffee disease detection system (CDDS) interacts with external users such as farmers, officers, highlighting the flow of information between them and the system. The context diagram of the CDDS is a single process entity surrounded by its four external actors Farmer, Extension Officer, Researcher, and Administrator plus the browser's Service Worker component. Data flows are shown at the highest level of abstraction.

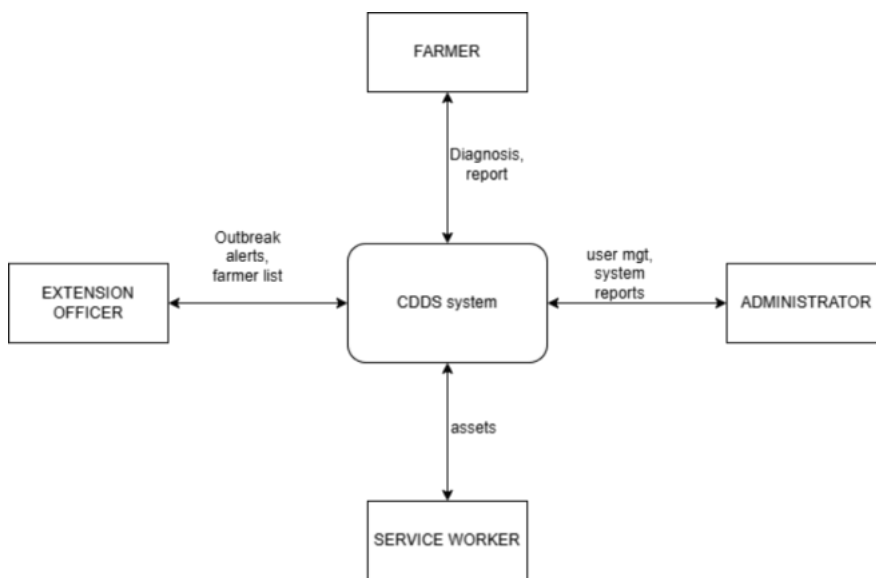


Figure 2: Context Diagram (Level 0 DFD) of CDDS

Key flows: The Farmer submits selected symptoms, district, and variety information; the system returns a ranked diagnosis, management plan, and PDF report. The Extension Officer accesses district-level diagnosis aggregates and farmer lists. The Researcher receives anonymised system-wide analytics and CSV export data. The Administrator manages users and the knowledge base. The Service Worker caches application assets and the knowledge_base.json for offline operation.

4.6 Data Flow Diagram

The Level 1 DFD decomposes the CDDS into its nine major processes, showing the data stores they interact with and the flows between them.

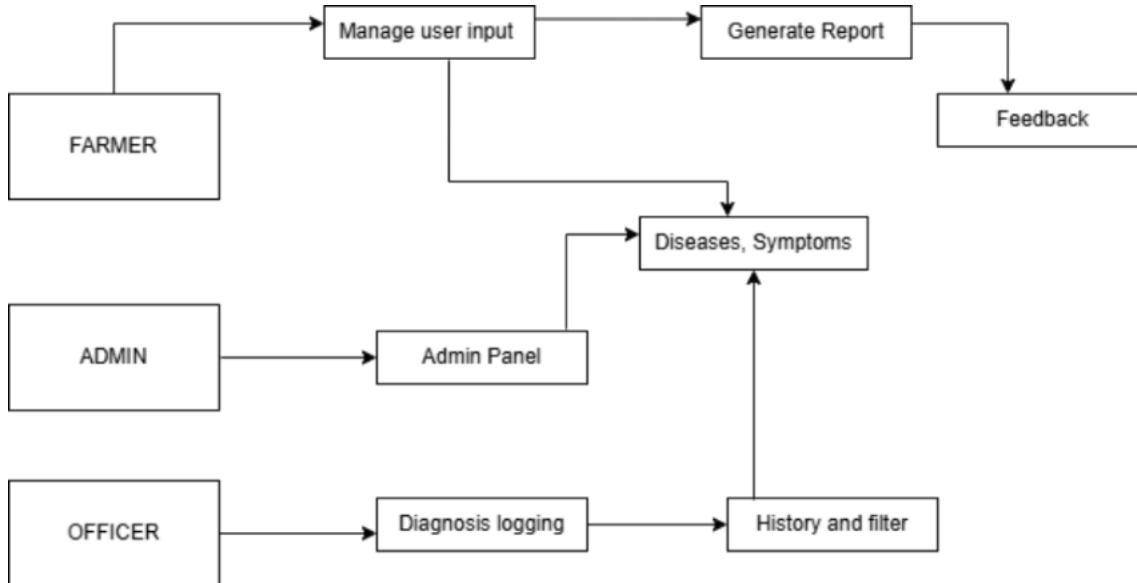


Figure 3: Level 1 Data Flow Diagram of CDDS

Process descriptions:

- User Authentication:** Handles login and registration, reading from and writing to DS1 (users). On successful login, creates a session with the user's ID, name, role, and district.
- Symptom Input:** Presents the symptom selection form to logged-in users. Collects the array of selected symptom IDs, the farmer's district, and coffee variety.
- Diagnosis Engine:** The core process. Reads disease-symptom rules and weights from DS3, scores all diseases against selected symptom IDs using the weighted algorithm, normalizes scores to confidence percentages, and returns ranked results.
- Report Generation:** Formats the diagnosis result, management actions, and matched symptoms into a structured HTML page. Triggers jsPDF in the browser for PDF generation.
- Diagnosis Logging:** Writes each completed diagnosis to DS2 (diagnosis_log) with user ID, disease name, confidence, district, variety, and timestamp.
- History & Filter:** Reads diagnosis_log with role-based filtering. Farmers see user_id = own, Officers see district = own district, Researchers and Admins see all records.
- Admin Panel:** Reads and writes DS1 (users) and DS3 (diseases/symptoms/rules) to support user management and knowledge base editing.

4.7 The Use Case Diagram

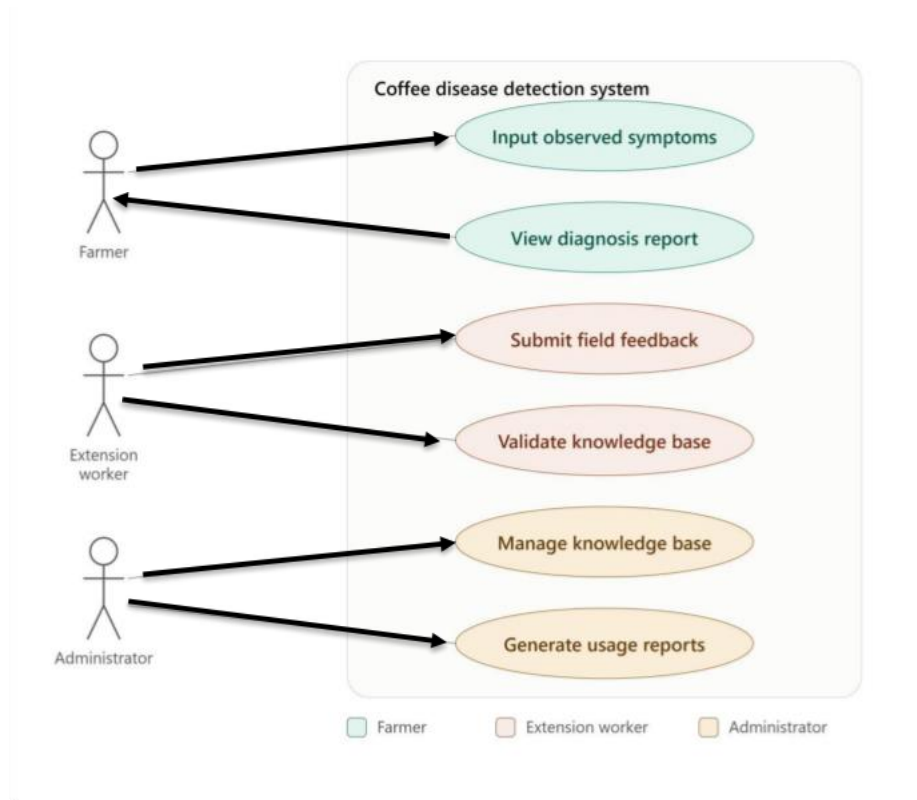


Figure 4: Use case diagram.

4.8 Entity Relationship Diagram

The system used MySQL as the main database during the prototyping phase. The database stores farmer details, disease symptoms, prevention and treatment. Development tools such as Visual Studio Code, windows, UML and Google Chrome were used during coding and testing.

The ERD illustrates the logical data model of the CDDS database, showing all 10 entities, their attributes, primary and foreign keys, and relationships with cardinalities.

Key relationships:

- users (1) —< diagnosis_log (N): One user may have many diagnosis records. This is the primary data ownership relationship.
- users (1) — (1) farm_profiles: Each farmer has exactly one farm profile. This is an optional one-to-one extension of the users entity.

- diseases (1) —< disease_symptoms (N) >— (1) symptoms: The disease_symptoms table is a junction entity resolving the many-to-many relationship between diseases and symptoms, with an additional weight attribute capturing the diagnostic importance of each symptom for each disease.
- diseases (1) —< management (N): Each disease has multiple associated management actions, classified by type (treatment, prevention, cultural).
- diagnosis_log (1) —< feedback (N): Users may submit accuracy feedback on any diagnosis log entry.
- users (1) —< officer_assignments (N): An extension officer may be assigned to multiple districts or sub-counties over time.
- users (1) — (1) researcher_access: Researchers have an approval and institution record linked to their user account.

4.9 The Entity Relationship Diagram (ERD)

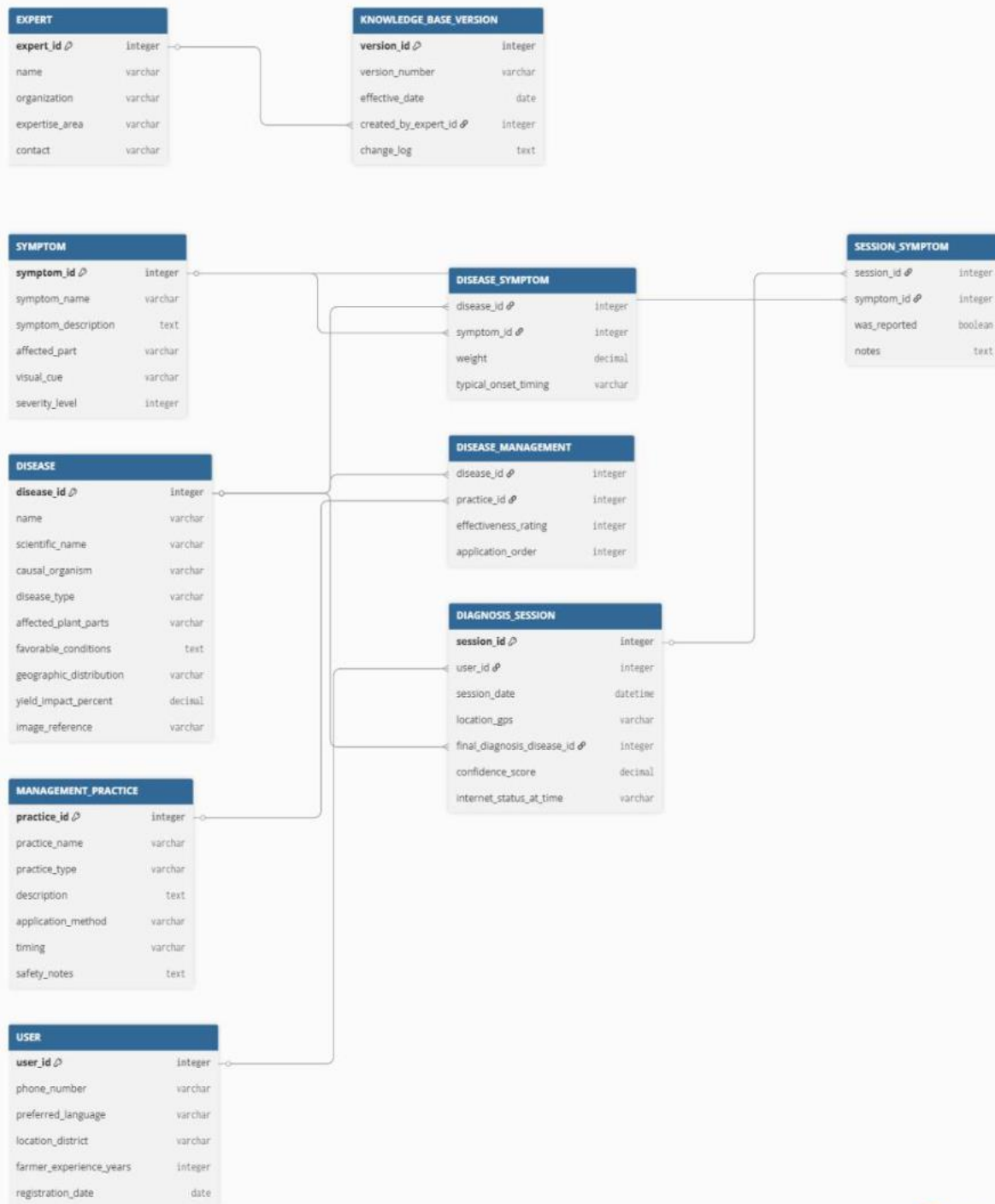


Figure 5: Entity Relationship Diagram (ERD) of CDDS

4.10 Database Schema

The CDDS database comprises ten tables. The primary tables and their key attributes are summarised below:

<i>Table</i>	<i>Primary Key / Key Columns</i>	<i>Description</i>
users	id, (UNIQUE) email	Stores all user accounts for the 4 roles. Includes bcrypt password_hash, role, enum, district, organisation, and is_active flag.
diseases	id	Defines each disease with name, causal organism, affected parts, yield impact, description, severity level, spread mode, and peak season.
symptoms	id	Defines each of the 26 observable symptoms with name, description, affected plant part, and display icon.
disease_symptoms	id, FK disease_id, FK symptom_id	Junction table constituting the knowledge base. Each row links a disease to a symptom with a weight (0.3– 1.0) indicating
management	id, FK disease_id	Contains management actions per disease, typed as treatment / prevention / cultural, with a priority integer for display ordering.
diagnosis_log	id, FK user_id	Records every diagnosis session. Stores user_id, symptom IDs as CSV, disease name, confidence score, district, variety, and language used.
feedback	id, FK log_id	Captures user feedback on diagnosis accuracy: whether the result was correct, the actual disease (if different), and freetext notes.
farm_profiles	id, FK user_id (UNIQUE)	Optional one-to-one extension of users for farmers. Stores village, GPS coordinates, farm size, coffee variety, tree count, and agronomic flags.
officer_assignments	id, FK officer_id	Records district/sub-county assignments for extension officers. Supports multi-district officers.

CHAPTER FIVE: SYSTEM IMPLEMENTATION AND TESTING

5.1 Introduction

This chapter presents the results obtained from the design, development, and testing of the Coffee Disease Detection System (CDDS) for Mount Elgon Slopes Coffee Farmers in Mbale, Uganda. It shows how the system met the study objectives by improving coffee disease identification, providing timely disease management recommendations, and supporting communication between coffee farmers and extension workers. The chapter outlines key system features, including user authentication, farmer management, coffee leaf image uploading, disease detection, disease management recommendations, and reporting functionalities.

In addition, the chapter presents system outputs such as screenshots, sample disease detection results, and reports generated during testing. The performance and usability of the system were also evaluated based on its ability to address challenges associated with traditional coffee disease identification methods, such as delayed diagnosis, limited access to extension services, and inaccurate disease identification. Overall, the chapter demonstrates the effectiveness of the CDDS in supporting coffee farmers, extension workers, and administrators in coffee disease identification and management.

5.2 Interface Design

This section presents the interface design of the Coffee Disease Detection System (CDDS) developed for Mount Elgon Slopes Coffee Farmers in Mbale, Uganda. The system interfaces were designed to be simple, user-friendly, and easy to navigate to support effective interaction among coffee farmers, extension workers, and administrators.

The login interface was designed to allow registered users to securely access the system by entering their username and password. It ensured that only authorized users could access system functionalities according to their assigned roles.

The dashboard interface provided an overview of system activities and quick access to key functions such as farmer records, disease detection, coffee management education, disease information, advisory services, and reports. It enabled users to access relevant activities from a central interface.

The farmer management interface allowed administrators and extension workers to register, view, update, and manage coffee farmer information. It provided access to relevant farmer and farm details required for disease monitoring and advisory support.

The disease detection interface allowed farmers to upload or capture images of coffee leaves suspected of being affected by disease. The system analyzed the uploaded image and displayed the detected disease.

The disease results interface displayed the detected coffee disease and relevant information about the condition. It also provided recommended disease management and control measures to help farmers take appropriate action.

The coffee education interface provided farmers with educational information on coffee farming and management practices. The information covered areas such as proper coffee planting, field management, pruning, weed control, pest and disease prevention, fertilizer application, harvesting, and post-harvest handling. This interface enabled farmers to access useful information that could improve coffee production and maintain healthy coffee plants.

The extension worker interface enabled extension workers to view farmers' disease detection results and provide additional guidance and recommendations. It also supported extension workers in educating farmers on appropriate coffee management practices and responding to farmers' questions and concerns.

The report interface provided summarized information about farmers, detected diseases, and disease occurrences. It supported monitoring, analysis, and decision-making by presenting relevant information in an organized format.

Overall, the interface design focused on simplicity, consistency, accessibility, and usability to enable coffee farmers, extension workers, and administrators to perform their respective tasks efficiently while supporting coffee disease detection, farmer education, and improved coffee management practices.

5.3 Development Environment and Tools

Category	Tool / Technology	Purpose
Web Server	XAMPP 8.2 /	Local development server; serves PHP
	Apache 2.4	files at localhost
Server	PHP 8.2	Server-side logic, routing, engine,
Language		authentication
Database	SQLite 3	Zero-setup file-based database for
(Dev)		development and deployment
Database	MySQL 8.0	Production database; switchable via
(Prod)		config.php constant

Front-end	HTML5 + CSS3 +	UI, symptom form, offline intercept,
PDF	Vanilla JS jsPDF 2.5.1 (CDN)	sidebar Client-side PDF generation in browser;
Generation		works offline
Offline	Service Worker	Caches app shell + knowledge_base.json
Cache	(sw.js)	for offline use
Offline DB	sql.js (SQLite in	Optional browser-side SQLite for offline
IDE	WASM) Visual Studio Code	query execution Code editing with PHP Intelephense
Version	Git + GitHub	extension Source code management and version
Control		tracking
OS	Windows 11	Development and testing environments

5.4 Key Implementation Modules

5.4.1 Weighted Diagnosis Engine (includes/engine.php)

The core diagnosis function, `diagnose (array $symptom_ids, PDO $pdo)`, executes the following algorithm:

1. Build a SQL IN clause from the selected symptom IDs.
2. Execute a single SQL query joining diseases and disease_symptoms, summing weights for matched symptoms per disease.
3. For each disease in the result set, query the maximum possible score (SUM of all weights for that disease) and compute: $\text{confidence} = (\text{matched_score} / \text{max_score}) \times 100$.
4. Sort results by descending confidence and return the ranked array.

The `getMatchedSymptoms()` function returns a second query specifically listing which symptoms matched the primary disease, including their weights enabling the hallmark symptom highlighting on the results page.

5.4.2 Role-Based Authentication

The authentication module implements RBAC using PHP sessions. Key functions:

requireLogin(): Redirects unauthenticated requests to `auth/login.php`, preserving the original destination URL in the `?next` parameter.

RequireRole (string \$role): Calls `requireLogin()` then verifies the session role matches the required role; redirects to the appropriate dashboard with an `access_denied` flag if not.

LoginUser (array \$user): Calls `session_regenerate_id(true)` to prevent session fixation attacks before writing the user's ID, name, email, role, and district to

the session.

DashboardUrl(): Returns the correct dashboard URL for the current user's role, used after login for the redirect.

5.4.3 Offline Architecture

The offline system comprises three components working in concert:

sw.js (Service Worker): Intercepts all GET requests. On network success, caches the response. On network failure, serves from cache. POST requests (form submissions) are never intercepted, preventing stale diagnosis submissions.

offline-engine.js: A JavaScript reimplementation of engine.php's diagnose() function. It fetches knowledge_base.json (from cache if offline), iterates through rules, computes weighted scores, and returns ranked results identically to the PHP engine.

app.js offline intercept: On the index.php form submission event, if navigator.onLine is false, app.js calls diagnoseOffline() from offline-engine.js, then calls renderOfflineResults() to display results using the same HTML structure as the online diagnose.php page.

5.5 Authentication Flow

The registration form collects role-specific fields using JavaScript-controlled show/hide sections. On submission, the server validates all inputs, hashes the password with password_hash (PASSWORD_BCRYPT) inserts the user record, and simultaneously creates the appropriate supporting record (farm_profiles for farmers, officer_assignments for officers, researcher_access for researchers). The system then redirects to login.php with a registered=true confirmation message. Login validates credentials using password_verify() against the stored bcrypt hash. On success, the session is regenerated and the user is redirected to dashboardUrl() a role-based URL that maps each role to its specific dashboard file.

5.6 Registering Accounts and Login

CDDS

This page couldn't be translated
Try again Translate options
Google Translate

EN LG

Tukusanyukidde ku CDDS

Tusobozesa abalimi ba kaawa mu Uganda okukebera endwadde mangu —
n'awatali yintaneti.

Yingira

Erinnya lyo

immy@gmail.com

Ekigambo ky'ekyama

Koola Akawunti y'Omulimi

Erinnya lyo

immy@gmail.com

Erinnya Lyo Lyonna

immy@gmail.com

Password

Login

immy@gmail.com

Full Name

Your full name

Phone Number

e.g. 0772123456

District

e.g. Mbale

Password

Register

Figure 6: Register Accounts form

5.7 Welcome page supporting English and Luganda.

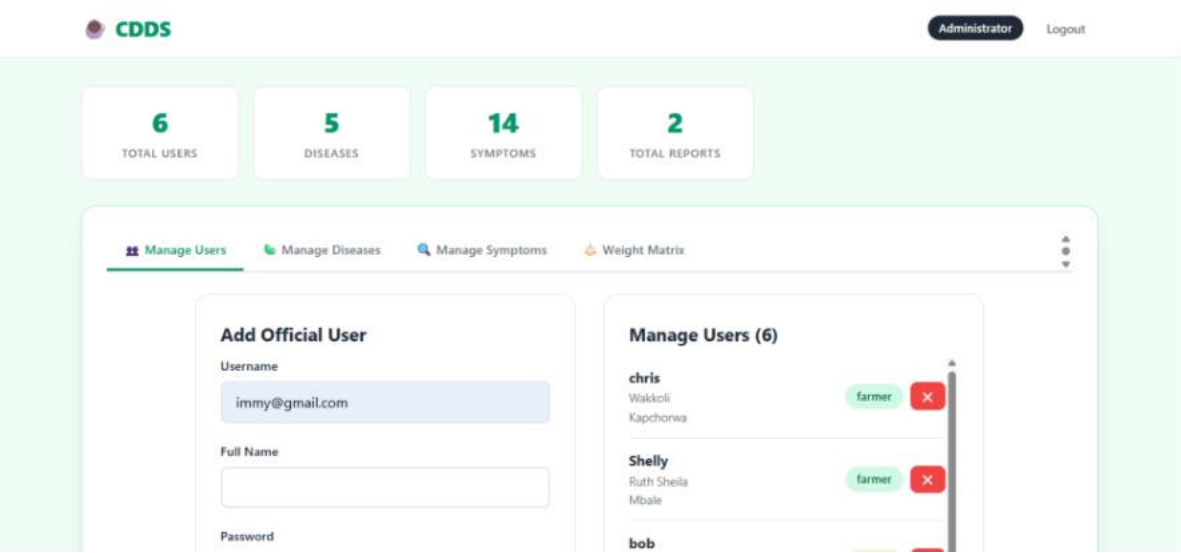


Figure 7: Administrator welcome page

5.7 A Diagnosis Report of a specific Coffee Diseases

CDDS — Diagnosis Report
Busitema University Coffee Disease Detection System

Date: 2026-04-21 04:39:48

Farmer: chris

Diagnosis Result

Coffee Twig Borer

Confidence Score: 19 points

Description:

A small ambrosia beetle (*Xylosandrus compactus*) that bores into young shoots and twigs, causing them to wilt and die back. Creates small round entry holes. Damage is most severe in shaded and humid conditions. Affects both Arabica and Robusta in Uganda.

Recommended Treatment:

Prune and burn all affected twigs and branches immediately. Apply contact insecticides to affected areas. Reduce excessive shading. Maintain proper plant spacing and field sanitation.

Figure 8: Disease diagnosis report for the coffee plant

CHAPTER SIX: CONCLUSION, LIMITATIONS AND RECOMMENDATIONS.

6.1 Introduction

This chapter presents the **conclusions, limitations, and recommendations** arising from the development and implementation of the **Coffee Disease Detection System (CDDS)** for **Mount Elgon Slopes Coffee Farmers in Mbale, Uganda**. The chapter summarizes the major findings of the study in relation to the specific objectives, highlights the limitations encountered during the design, development, and implementation of the system, and provides recommendations for improving the system and its use. It also identifies areas for **future research and further development**, particularly in enhancing coffee disease detection, farmer education, and extension support.

6.2 Discussion of Results

The findings from the literature review, system design, implementation, testing, and validation processes are discussed in this section in relation to the specific objectives of the study and the existing literature reviewed in Chapter Two.

6.2.1 Objective 1: To review existing literature of coffee diseases in Uganda

The study began by reviewing existing literature on coffee diseases affecting coffee production in Uganda, with particular attention to diseases that affect coffee farmers in the **Mount Elgon Slopes region of Mbale**. The review focused on the symptoms, causes, effects, prevention, and management practices associated with major coffee diseases.

The literature review established that coffee diseases can negatively affect plant health, coffee yield, and the quality of coffee produced by farmers. It also revealed that identifying coffee diseases can be challenging, particularly for farmers with limited access to agricultural extension services and technical knowledge. Farmers may rely on personal experience or traditional methods to identify diseases, which can result in delayed or incorrect diagnosis and inappropriate management practices.

The reviewed literature provided the knowledge base for identifying the coffee diseases, symptoms, and management practices incorporated into the CDDS. It also guided the development of the symptom-based disease identification component, where farmers provide symptoms observed on affected coffee plants and the system provides the most likely disease diagnosis.

Therefore, the first objective was achieved by establishing relevant knowledge about coffee diseases in Uganda and identifying the information required to develop a computerized system for disease identification and management.

6.2.2 Objective 2: To design the Coffee Disease Detection System

Following the literature review, the **Coffee Disease Detection System (CDDS)** was designed to support **coffee farmers, extension workers, and administrators** in coffee disease identification and management. The system design focused on providing an accessible platform through which farmers could enter symptoms observed on affected coffee plants and receive information about the likely disease and recommended management practices.

System models, including **Use Case Diagrams, Data Flow Diagrams (DFDs), Entity Relationship Diagrams (ERDs), and user interface designs**, were developed to represent the system structure, data flows, database relationships, user interactions, and system processes.

The system design incorporated key components including user authentication, farmer management, symptom entry, disease identification, disease information, management recommendations, coffee management education, extension worker support, and reporting. Role-based access was also incorporated to ensure that farmers, extension workers, and administrators could access functionalities relevant to their responsibilities.

The design also incorporated a **farmer education component** to provide information on good coffee management practices. This included information on disease prevention, pruning, weed control, fertilizer application, field management, harvesting, and post-harvest handling.

The design therefore provided a structured and user-friendly platform for supporting coffee farmers in disease identification while also strengthening access to coffee management information and extension services. The second objective was consequently achieved through the design of a system that addressed the identified needs of the target users.

6.2.3 Objective 3: To implement a system capable of accurately detecting diseases and diagnosing

The designed **Coffee Disease Detection System (CDDS)** was implemented as a web-based system that enables farmers to identify coffee diseases based on the **symptoms observed on affected coffee plants**. Farmers enter the symptoms they observe through the system, and the system compares the entered symptoms with the available disease information to determine the most likely coffee disease.

The system provides the identified disease together with relevant information about its symptoms, possible causes, prevention measures, and recommended management practices. This enables farmers

to obtain timely information that can assist them in taking appropriate measures to control and manage coffee diseases.

The system also implemented a **coffee management education module** through which farmers could access information on appropriate coffee farming practices. This module was intended to improve farmers' knowledge and support better management of coffee plants beyond disease identification.

Extension workers were provided with functionalities to support farmers by providing additional guidance on identified diseases and general coffee management practices. Administrators were provided with functionalities for managing users, disease information, symptoms, recommendations, and other system activities.

The implementation demonstrated that a symptom-based computerized approach can provide farmers with an accessible means of obtaining preliminary coffee disease identification and appropriate management information. Therefore, the third objective was achieved through the implementation of a CDDS capable of **symptom-based disease identification, diagnosis support, farmer education, and extension support**.

6.2.4 Objective 4: To test and validate the system

The implemented CDDS was tested and validated to determine whether it met the specified functional and non-functional requirements. Testing focused on major system components, including user authentication, farmer registration, symptom entry, disease identification, disease information, management recommendations, farmer education, extension worker services, and report generation.

The disease detection component was tested using different combinations of **coffee disease symptoms entered by users**. The test results were examined to determine whether the system could correctly match the reported symptoms with the corresponding coffee diseases and provide appropriate management recommendations.

The testing results demonstrated that the system could receive symptoms observed by farmers, compare the entered symptoms with the stored disease information, and provide a likely disease diagnosis together with relevant management information. The interfaces were also tested to ensure that farmers, extension workers, and administrators could navigate and perform their respective tasks effectively.

The validation process further demonstrated that the CDDS could address some challenges associated with traditional coffee disease identification, particularly **delayed access to disease information, limited access to extension services, and farmers' difficulties in identifying diseases from observed symptoms**. The integration of symptom-based disease identification, farmer education, and extension worker support provided a more comprehensive approach to coffee disease management.

Overall, the testing and validation results confirmed that the CDDS met its intended functional requirements and achieved the fourth objective of the study. The findings demonstrate the potential of a **symptom-based computerized disease detection system** to support timely coffee disease identification, farmer education, and improved coffee management practices.

6.3 Summary of Achievements

This project has successfully designed, implemented, and tested the Coffee Disease Detection System (CDDS) a web-based, offline-capable, role-based decision support system for coffee disease identification in Uganda. The system meets all stated functional and non-functional requirements.

The key contributions of this work are:

A working weighted rule-based expert system covering 5 diseases, their symptoms, and diagnostic rules, capable of returning confidence-ranked diagnoses in under 2 seconds.

A Progressive Web App architecture that enables full diagnostic and PDF reporting functionality without internet connectivity, addressing the principal barrier to digital tool adoption in Uganda's highland coffee-growing zones.

A role-based authentication system with distinct user types, each with a personalized dashboard and data-scoped history access the first such multi-stakeholder architecture documented for a Uganda-specific coffee disease platform.

A browser-side PDF management report generator (jsPDF) that produces professional, printable reports in both online and offline modes.

A multilingual interface supporting English and Luganda reducing language barriers to adoption among rural farmers.

6.4 Conclusion

The study successfully achieved its objectives by reviewing existing literature on coffee diseases in Uganda and subsequently designing, implementing, testing, and validating the **Coffee Disease Detection System (CDDS)** for **Mount Elgon Slopes Coffee Farmers in Mbale, Uganda**.

The developed system addressed challenges associated with traditional coffee disease identification by providing a centralized and accessible platform where farmers can enter **symptoms observed on affected coffee plants** and obtain information on the likely disease and appropriate management measures. The system also provided educational information on coffee management practices and enabled extension workers to provide additional guidance to farmers.

Overall, the study demonstrated that a **symptom-based computerized disease detection system** can support timely coffee disease identification, improve farmers' access to disease management information, enhance farmer education, and strengthen extension support. The CDDS therefore provides a useful digital approach for supporting improved coffee disease management among farmers on the **Mount Elgon Slopes in Mbale, Uganda**.

6.5 Limitations

Image-based diagnosis: The current system relies entirely on symptom selection by the user. It does not yet incorporate computer vision for automated symptom detection from photographs, which could improve accuracy and reduce user effort.

Knowledge base breadth: Only five diseases are covered. Uganda's coffee crop is subject to additional threats including Coffee Ring Spot Virus, root-knot nematodes, and antestia bugs, which are not yet in the system.

GPS-based disease mapping: While district is captured, GPS coordinates are not yet used to produce geographic outbreak maps.

Push notifications: The system cannot proactively alert farmers or officers to new diagnoses or outbreak thresholds without an active browser session.

Validated clinical accuracy study: The confidence scores are based on expert-assigned weights rather than statistically validated training data. A formal accuracy study comparing CDDS diagnoses to pathologist-confirmed field diagnoses is needed.

6.6 Future Work and Recommendations

The following areas are recommended for future enhancement of the Coffee Disease Detection System (CDDS):

Image-Based Disease Detection: Integrate image-based disease detection using **Convolutional Neural Networks (CNNs)** to classify coffee diseases from photographs of affected leaves. This would reduce reliance on manually selected symptoms and improve accessibility for users with limited disease-identification knowledge.

GPS-Based Disease Outbreak Mapping: Incorporate **GPS-based outbreak mapping** using **Leaflet.js** to visualise the geographical distribution of reported disease cases on district maps. This would enable extension officers to monitor disease patterns and identify potential outbreak hotspots through their dashboards.

Push Notification Support: Implement push notifications using the **Web Push API** to alert extension officers whenever high-confidence diagnoses of critical diseases, particularly **Coffee Wilt Disease (CWD)** and **Coffee Berry Disease (CBD)**, are recorded within their respective districts.

Formal Knowledge Base Validation: Conduct a structured validation study of the system's disease knowledge base in collaboration with **UCDA plant pathologists** using confirmed field samples. This would help assess and improve the accuracy and reliability of the disease diagnosis rules.

Integration with National Disease Surveillance Systems: Integrate the CDDS with **UCDA's national coffee disease surveillance and reporting system** to enable diagnosis data generated at the farmer and extension-worker levels to contribute to national disease monitoring, reporting, and response frameworks.

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APPENDIX.

A: FULL QUESTIONNAIRE (Data Collection Instrument)

The questionnaire reproduced in Chapter 3, Section 3.3 constitutes Appendix A in its entirety. It was administered in both English and Luganda. A total of 53 questionnaires were distributed.

Sample Questionnaire

The following questionnaire was used for data collection from coffee farmers and agricultural professionals. It was administered in English, with a Luganda translation available for farmers in central districts.

BUSITEMA UNIVERSITY – FACULTY OF SCIENCE AND EDUCATION

DEPARTMENT OF COMPUTER STUDIES

Odoi Immanuel Reg No: BU/UP/2023/3681 is carrying out a study to develop a Coffee Disease Detection System (CDDS). You are humbly requested to fill in this Data Collection Questionnaire. Thank you
Instructions.

1. This questionnaire is part of an academic research project at Busitema University.
2. It aims to gather information for the design of a Coffee Disease Detection System.
3. Participation is voluntary and completely confidential. No personal identifying information will be shared.
4. Please answer all questions as honestly and completely as possible. Tick (✓) or circle your chosen answer.

SECTION A: RESPONDENT BACKGROUND

A1. What is your role in the coffee value chain?

- ☐ Coffee Farmer / Grower
☐ Agricultural Extension Officer (UCDA / District)
☐ Researcher / Academic (University / NARO / NaCRRI)
☐ Other (please specify): _____

A2. In which district are you primarily based / do you farm?

- ☐ Mbale ☐ Kapchorwa ☐ Sironko ☐ Bulambuli ☐ Kween ☐ Bushenyi
☐ Kasese ☐ Wakiso ☐ Other: _____

A3. What type of coffee do you grow / work with? (Tick all that apply)

- ☐ Robusta (Coffea canephora)
☐ Arabica (Coffea arabica)

☐ Both

☐ Not applicable

A4. What is the approximate size of the farm(s) you are responsible for?

☐ Less than 0.5 acres ☐ 0.5 – 1 acre ☐ 1 – 3 acres ☐ 3 – 5 acres

☐ More than 5 acres ☐ Not applicable

A5. What is your highest level of formal education?

☐ No formal education ☐ Primary level ☐ Ordinary Level (O-Level)

☐ Advanced Level (A-Level) ☐ Diploma / Certificate ☐ Degree or higher

A6. Do you own or regularly use a mobile phone / smartphone?

☐ Yes, a smartphone (Android/iPhone)

☐ Yes, a basic (feature) phone only

☐ No, I do not own a mobile phone

A7. How would you describe your ability to use the internet?

☐ I use it daily with confidence

☐ I use it occasionally but need help sometimes

☐ I rarely use it / I am not comfortable with it

☐ I have never used the internet

SECTION B: DISEASE IDENTIFICATION & CURRENT PRACTICES

B1. How often do you observe signs of disease on your coffee plants?

☐ Very frequently (every few weeks)

☐ Occasionally (once or twice per season)

☐ Rarely (once a year or less)

☐ Never or not sure

B2. Which of the following coffee diseases are you familiar with? (Tick all you recognise)

☐ Coffee Leaf Rust (yellow powder on leaves)

☐ Coffee Berry Disease (dark spots on berries)

☐ Coffee Wilt Disease (sudden plant wilting / death)

☐ Black Rot (dark lesions on stems and berries)

☐ Coffee Sooty Mould (black coating on leaves)

☐ I am not familiar with specific disease names

B3. When you observe symptoms of disease on your plants, what do you normally do first?

☐ I wait and monitor to see if it gets worse

☐ I call or visit a UCDA extension officer

- ☐ I ask a fellow farmer for advice
- ☐ I apply a fungicide or pesticide I already have
- ☐ I search the internet for information
- ☐ Other: _____

B4. How long does it typically take from when you notice disease symptoms to when you receive professional advice or treatment guidance?

- ☐ Same day ☐ 1 – 3 days ☐ 4 – 7 days ☐ 1 – 2 weeks
- ☐ More than 2 weeks ☐ I rarely receive professional advice

B5. Has incorrect disease identification ever led to significant crop loss on your farm or on a farm you managed?

- ☐ Yes, definitely
- ☐ Yes, possibly
- ☐ No
- ☐ Not sure / not applicable

B6. How confident are you in your ability to correctly identify the disease affecting your coffee plants from symptoms alone?

- ☐ Very confident — I can identify most diseases accurately
- ☐ Somewhat confident — I can identify common diseases
- ☐ Not very confident — I often struggle to identify correctly
- ☐ Not at all confident — I cannot identify diseases

B7. Please rate the difficulty of identifying each of the following diseases without professional help (1 = Very Easy, 5 = Very Difficult):

Disease	1 (Easy)	2	3	4	5 (Difficult)
Coffee Leaf Rust	☐	☐	☐	☐	☐
Coffee Berry Disease	☐	☐	☐	☐	☐
Coffee Wilt Disease	☐	☐	☐	☐	☐
Black Rot	☐	☐	☐	☐	☐
Coffee Sooty Mould	☐	☐	☐	☐	☐

SECTION C: SYMPTOM VOCABULARY AND KNOWLEDGE BASE DESIGN

This section helps us understand how farmers describe disease symptoms in their own words.

C1. What visual signs would make you suspect that your coffee plants have a disease? (Write in your own words or tick all that apply)

Symptom	Have you observed this? (Y/N)
Yellow or orange powder on leaf undersides	☐ Yes ☐ No
Yellow spots on upper leaf surfaces	☐ Yes ☐ No
Leaves turning yellow and falling off early	☐ Yes ☐ No
Dark sunken spots on green coffee berries	☐ Yes ☐ No
Berries dropping before they are ripe	☐ Yes ☐ No
Plant wilting suddenly without reason	☐ Yes ☐ No
Brown discolouration inside cut stem	☐ Yes ☐ No
Dark lesions on stems or branches	☐ Yes ☐ No
Black sooty coating on leaves	☐ Yes ☐ No
Mummified or shrunk berries on plant	☐ Yes ☐ No
White fuzzy growth on leaves	☐ Yes ☐ No
Stunted plant growth	☐ Yes ☐ No
Roots brown or black when dug up	☐ Yes ☐ No
Insects (scale, mealybugs) on stems	☐ Yes ☐ No

C2. In your local language, how would you describe plants with yellow leaves and orange powder on the underside of the leaves?

Luganda:

Your language:

SECTION D: TECHNOLOGY AND SYSTEM DESIGN PREFERENCES

D1. Have you ever used a mobile phone or computer to get information about crop disease management?

- ☐ Yes, frequently
- ☐ Yes, occasionally
- ☐ I have tried but found it difficult
- ☐ No, never

D2. Are there areas on or near your farm where mobile internet is unavailable or unreliable?

- ☐ Yes, most of the time
- ☐ Yes, sometimes (especially in valleys / mountainous areas)

☐ Rarely — internet is mostly available

☐ No, internet is always available

D3. If a mobile or computer application could help you identify coffee diseases, which features would be most important to you? (Rank 1 = Most Important, 5 = Least Important)

Feature	Ranking (1–5)
Works without internet (offline mode)	_____
Available in my local language (Luganda)	_____
Shows clear pictures or icons for symptoms	_____
Provides a step-by-step management plan	_____
Generates a printable/downloadable report	_____
Shows history of previous diagnoses	_____
Connects me with an extension officer	_____
Shows which disease is most likely with a confidence level	_____

D4. Which language would you prefer the application to use?

☐ English only

☐ Local language only (please specify: _____)

☐ Both English and local language

☐ No preference

D5. Which device would you most likely use to access a coffee disease detection app?

☐ Android smartphone

☐ Feature phone (SMS/basic browser)

☐ Shared community computer / tablet

☐ Extension officer's device

D6. Would you be willing to register and create a personal account to use the system?

☐ Yes, definitely

☐ Yes, if registration is simple and short

☐ Maybe — if there is a strong benefit

☐ No — I prefer to use it without registering

Thank you sincerely for your time and participation.

B: FULL WORKPLAN AND THE TIMELINE

Appendix B consists of the work plan and timeline

Workplan and timeline.

Phase	Activity	Deliverable	Duration in weeks
1	Literature review, expert interviews, farmer field surveys, knowledge	Disease knowledge base document	1–2
2	Knowledge base design, interface prototyping, algorithm design, participatory design with farmers	Validated knowledge base; system design document; UI prototypes	2–3
3	Front-end development, back-end development, inference engine implementation, report generation module	Functional CDDS prototype	3–4
4	Unit testing, integration testing, user acceptance testing, field pilot in 4	Validated CDDS with testing reports and SUS scores	4–5
5	Full deployment farmer training, workshops, data collection, analysis, thesis	Deployed system; training materials; final report and publications	5–6

C: ESTIMATED BUDGET

ITEM	CATEGORY	UNITS	COST (USHS.)
Field survey transport and accommodation (1 district)	Field Research	1 District	50,000
Expert interview facilitation	Data Collection		30,000
Survey printing and data collection materials	Data Collection	50 forms	50,000
Software development environment and cloud	Development	2 weeks	50,000
System testing and validation activities	Testing		10,000
Training materials printing and translation	Deployment	6	15,000
Research fees publication.	Dissemination	2 papers	≈45,000
Miscellaneous (10%)			25,000
TOTAL ESTIMATED BUDGET			225,000