

Personalized Digital Nutrition Support for Diabetic Inpatients

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Background and Purpose: Malnutrition is a major concern among diabetic inpatients and can complicate treatment and recovery. Personalized nutritional interventions are therefore important to meet individual dietary needs. Digital-based personalized nutrition systems can support this process through meal recommendations and activity monitoring. This study aimed to assess system requirements and develop a digital-based personalized nutrition system for diabetic inpatients. Specifically, it sought to identify requirements considered necessary by nutritionists, social workers, restaurant staff, and data managers; translate these requirements into a system architecture and working prototype; and assess the usability and perceived validity of the prototype among intended users.

Methods: A qualitative approach using in-depth interviews was employed to identify clinical and system requirements. The study was conducted at two referral hospitals in Kigali. The Harris–Benedict equation was used to estimate energy requirements and guide personalized meal planning. Agile software development was applied through planning, requirements analysis, design, development, and testing phases.

Results: A meal recommender system was developed that incorporated blood glucose levels, local foods, physical activity, glycemic index, and individual calorie requirements to generate personalized meal plans. The system aimed to support stable blood glucose levels and reduce sudden glucose spikes. All 10 participants who responded agreed that the prototype provided personalized meal recommendations for diabetic inpatients and helped identify potential food triggers. Additionally, 60% perceived potential for cost savings.

Conclusions: A digital-based personalized nutrition system can support nutritional management of diabetic inpatients and may contribute to improved dietary care and cost efficiency.

Keywords: Diabetes mellitus; Glycemic index; Malnutrition; Hospitalized patients; Food recommendation systems

1 Introduction

Malnutrition is a health problem of huge magnitude among hospitalized patients [1]. This is associated with numerous adverse clinical effects, such as higher illness rates and death rates, extended hospital stays, susceptibility to infections, loss of muscle mass, and inadequate wound healing [2]. Malnutrition pertains to the insufficient, excessive, or disproportionate consumption of energy and/or essential nutrients by an individual [3].

Among patients with diabetes mellitus specifically, malnutrition is both common and clinically consequential: a recent study conducted at the same two Kigali referral hospitals as the present work found that 55.3% of hospitalized patients with Type 2 diabetes were at risk of malnutrition [33]. Digital tools to support diabetes self-management have begun to emerge across the region, including mHealth applications for glucose tracking and self-management support in Ghana and Ethiopia [34] [35], yet most remain focused on self-monitoring and glycaemic logging rather than on structured, personalized meal planning for

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hospitalized patients, and few have been evaluated in the hospital in-patient setting typical of low-resource African health systems.

A critical reading of the existing food recommender literature exposes three recurring weaknesses that bear directly on the present work. First, the reviewed systems are built and validated almost exclusively in high-income or upper-middle-income settings and draw on food composition databases and dishes that do not correspond to the staples of East African hospital menus, so their recommendations are not directly transferable to this context [30]. Second, most report technical accuracy rather than clinical or workflow outcomes: a recent diabetes-focused food recommender system reached 94% classification accuracy using graph neural networks, but such metrics say little about whether a hospital nutritionist can act on the output within an existing ward routine [39]. Third, and most important for this study, the African evidence base concentrates on out-patient self-management rather than in-patient care. A systematic review of diabetes self-care interventions in sub-Saharan Africa found that technology-based components were typically educational or reminder-based rather than dietary-prescriptive [40], and a meta-analysis of mHealth for diabetes in Africa reported a significant reduction in HbA1c but drew on very few eligible trials, none of them set in hospital wards [41]. The present study therefore addresses a specific and under-served gap: a personalized, locally grounded meal recommendation system designed around the actual division of labour between nutritionists, social workers and restaurant staff in Rwandan referral hospitals, rather than a self-management tool transplanted into an African setting.

The World Health Organization (WHO) study has proven the links between risk factors for diabetes such as physical inactivity, a poor diet, a person's history, being soft and large, drinking alcohol, and smoking [4].

Diabetics must assume full responsibility for their care and treatment to adapt to evolving lifestyles [5]. This entails utilizing various technology-driven systems, including meal recommendation systems, monitoring, and tracking tools for physical activity, drug reminder notifications, that address any queries they may have regarding their condition [6].

In recent times, numerous recommendation systems have emerged with the aim of providing users with valuable wellness suggestions to enhance their overall health [7]. One such system is the proposed digital-based personalized nutrition assistant system designed for diabetic inpatients.

This system falls under the category of Artificial Intelligence (AI) and is designed to aid in diabetes management. It creates personalized meal plans for diabetic individuals, covering breakfast, lunch, and dinner. The system operates using a knowledge-driven approach, considering the user's information and a substantial knowledge database. Additionally, it factors in various elements like socio-economic status, cultural background, ethnicity, and location, with special attention to diabetic patients in the internal medicine department [8].

Typically, the task of evaluating individuals' nutrition requirements and offering nutritional guidance in both health and disease falls under the responsibility of nutritionists [9]. However, when a health facility is limited to having only one nutritionist on staff, it becomes increasingly challenging for them to assess the nutritional needs of every hospitalized patient [10].

It is crucial that all patients receive sufficient and suitable food and beverages according to their specific requirements [11]. Although many patients can handle their nutritional needs independently, there will be cases where some patients require assistance [12].

Therefore, it has become increasingly important for individuals to adopt a well-balanced and nutritious diet [13]. However, in today's fast-paced world, there is a shortage of nutritionists available to create personalized meal plans for every hospitalized diabetic patient and provide ongoing support and guidance based on their individual information [14].

The concept of personalized nutrition does not aim to modify existing nutritional guidelines, create customized food products, or transform food into medicine [15]. Instead, its purpose is to assist individuals in making lasting changes to their dietary behaviors that promote good health [16].

Personalized nutrition is an approach that helps each person achieve their desired health goals [17]. By tailoring healthy dietary recommendations to suit individuals' daily lives, personalized nutrition makes these suggestions more relevant and practical [18].

Persistent insufficient dietary consumption leads to malnutrition, a longstanding clinical concern that has been extensively studied in the past few decades [19]. Furthermore, undernutrition is individually linked to various adverse clinical consequences, encompassing elevated rates of complications, mortality, extended hospitalization, and escalated expenses [20]. Moreover, a compromised immune system, delayed

wound healing, muscle loss, elevated treatment expenses, and an elevated mortality rate are also associated with undernutrition [21].

Hence, the objective of this diabetes management system is to enhance the well-being of hospitalized patients by assessing their nutritional requirements and suggesting appropriate meals to fulfil these demands.

2 Materials and methods

The study was conducted at two referral hospitals in Kigali, Rwanda: the University Teaching Hospital of Kigali and King Faysal Hospital. It followed a systematic process consisting of multiple stages aimed at generating research findings and a working prototype. The overall research methodology is presented in Figure 1: The research approach comprised three main stages: defining the system requirements, creating the system architecture, and building a prototype. A qualitative descriptive design was used, drawing on a purposively sampled population of hospital staff involved in the nutritional care of diabetic in-patients, as detailed under Study Design, Study Population, and Sample Size below.

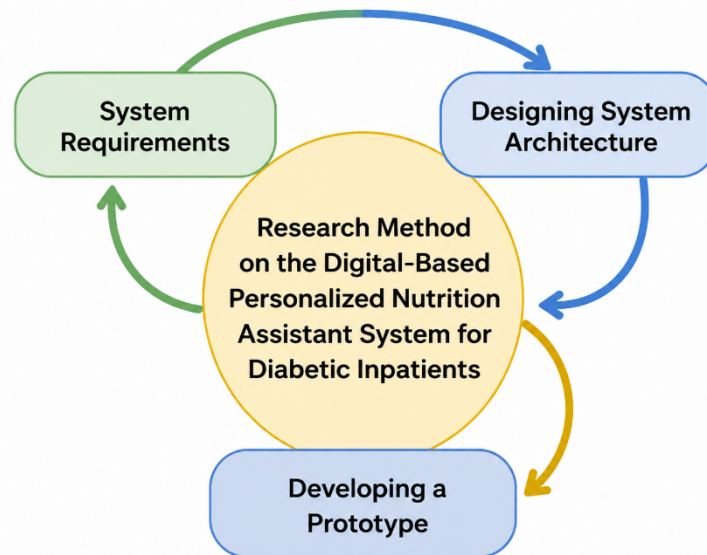


Fig. 1. Structure of the research methodology.

2.1 Study Design

Qualitative methods involving in-depth interviews conducted by a skilled facilitator were used to gather perceptions, opinions, and insights. These interviews employed flexible probing techniques to extract the information needed for designing the architecture and clinical requirements of the diabetes meal recommender system.

This overall aim was broken down into three specific research questions: (1) What system requirements do nutritionists, social workers, restaurant staff, and data managers identify as necessary for a digital personalized nutrition support system for diabetic in-patients? (2) How can these requirements be translated into a system architecture and prototype using Agile development? (3) How do intended users assess the usability and perceived validity of the resulting prototype?

2.2 Data set

The recommended diet for the user was determined using the Tanzania Food Composition Table [22], which maintains detailed nutritional data for each food item. The food composition data were extracted by the principal investigator between February and April 2023, in parallel with the qualitative data collection described under Data Collection below. In this diet recommendation system, the nutrient dataset was

tailored based on the user's BMI, basal metabolic rate, and glycaemic index of foods to accurately calculate and customize dietary recommendations.

2.3 Agile development system methodology

Agile development was used as a flexible and iterative software development methodology that emphasizes collaboration, adaptability, and continuous improvement. This methodology outlines the key principles and practices of Agile development as applied to developing the meal plan recommender system [23]. The decision to employ this methodology in the study was motivated by its capacity to facilitate iterative processes, ensuring ongoing feedback to enhance and deliver successive outcomes. The iterative approach encompassed continuous planning, testing, integration, and evolution. These phases encompass planning, requirements analysis, design, building, and testing.

2.4 Study setting

The study was conducted at two referral hospitals in Kigali (University Teaching Hospital of Kigali and King Faysal Hospital)

2.5 Study population

For qualitative data, the inclusion criteria for participating in the study were defined as staff working in selected hospitals, aged 18 years and above, for in-depth interviews, including nutritionists, social workers, data managers, and restaurant managers. Staff who had been in post for less than one month, and those unavailable for the full duration of the interview, were excluded.

2.6 Sample size

The principal investigator utilized purposive sampling to gather participants, and we continued to enrol new individuals until no new knowledge variation was observed. To confirm that saturation had been reached, we enrolled one more participant for a one-on-one interview. Eleven participants were interviewed in total. This is consistent with empirical evidence that thematic saturation in qualitative interview studies with a relatively homogeneous population and narrowly defined objectives is typically reached after approximately nine to seventeen interviews [42].

2.7 Data Collection

Data was collected through semi-structured, face-to-face in-depth interviews conducted between February and April 2023. The interview guide, developed based on established in-depth interview methodologies [24], consisted of two main sections. The first section gathered participant characteristics, including biographical details and self-assessed meal-planning knowledge. The second section explored participants' routine practices, needs, and expectations.

The interview process included two stages: first, a general discussion around the main topics was held. If participants were hesitant or provided overly broad answers, follow-up questions were asked to elicit more specific responses. These additional questions, derived from literature, focused on practical aspects of self-management systems.

To ensure linguistic and cultural accuracy, a professional translator translated the interview guide from English to Kinyarwanda. The translated guide was then pilot-tested with ten Rwandan diabetic patients, and adjustments were made based on their feedback to enhance clarity and relevance. And Written informed consent was obtained from all participants before the interviews.

2.8 Data analysis

Recorded data and scanned notes taken were uploaded to researchers' Google Drive, for data transcribing and translation which was done on a computer with a password.

All transcripts were read and reread to identify common words, phrases, and perceptions that were coded. Differences and similarities were highlighted in the text and organized into codes, sub-categories, and categories, we applied inductive category formation suggested within Mayring's method of qualitative content analysis [24].

2.9 Ethical consideration

Ethical approval was obtained from three bodies: the College of Medicine and Health Sciences (CMHS) Institutional Review Board on 14 November 2022 (Approval notice: CMHS/IRB/500/2022); the King Faysal Hospital IRB on 30 December 2022 (Approval Ref: KFH/2022/035/IRB); and the University Teaching Hospital of Kigali Ethics Committee, on 14th March 2023 (Approval Ref: EC/CHUK/046/2023).

3 Results

3.1 Characteristics of study participants

Eleven hospital staff took part in the study, and their characteristics are presented in Table 1. Most participants were male (7; 63.6%) and the remainder female (4; 36.4%). The sample was deliberately multidisciplinary, comprising nutritionists (4; 36.4%), data managers (3; 27.3%), social workers (2; 18.2%) and restaurant managers (2; 18.2%). This distribution spans the whole pathway along which an in-patient meal moves, from nutritional assessment, through data capture and record keeping, to meal preparation and service; it is this functional coverage, rather than the absolute number of interviews, that underpins the completeness of the requirements elicited. Participants were also formally qualified: 9 (81.8%) held a bachelor's degree, 1 (9.1%) a master's degree and 1 (9.1%) an advanced diploma. In terms of experience at the study facilities, 5 (45.5%) had served for 5-10 years and 4 (36.4%) for more than 10 years, so 9 of 11 respondents (81.8%) had at least five years of service, while only 2 (18.2%) had 1-5 years. Table 1 therefore describes an experienced, formally trained and functionally diverse group, which strengthens confidence that the routine practices reported below reflect established institutional workflows rather than the impressions of recently appointed staff. Two features of the sample should nonetheless be borne in mind when interpreting the findings: the predominance of male respondents, and the absence of ward nurses and attending physicians, whose perspectives on in-patient feeding were not captured.

Table 1. Characteristics of the study participants

Variables	Frequency n=11	Percentage %=100
Gender		
Female	4	36.4
Male	7	63.6
Educational Qualification		
Advanced Diploma	1	9.1
Bachelor	9	81.8
Masters	1	9.1
Participants Distribution		
Nutritionists	4	36.4
Social workers	2	18.2
Data managers	3	27.3
Restaurant managers	2	18.2
Years of services		
1 -5	2	18.2
6 -10	5	45.5
>10	4	36.4

3.2 Emerging themes from qualitative interviews

Three main themes were identified throughout the analysis, including (1) Knowledge and Awareness of Diabetic Meal Planning (2) Routine Practices in Nutritional Assessment and Meal Planning (3) Expectations and Needs for the Dietary Management System

3.2.1 Respondents' views on the knowledge and awareness of the diabetic meal plan

This theme captures respondents' understanding of how to design a meal plan for individuals with diabetes. Participants emphasized the importance of limiting refined carbohydrates, increasing dietary fiber, and selecting healthy fat and protein sources. They also recognized the need to avoid foods high in sugar, saturated and trans fats, and processed items, as these can hinder blood sugar control and negatively impact overall health.

"It's important to limit or avoid certain foods, especially those high in sugar, saturated and trans fats, and processed ingredients. These foods can make worse of blood sugar control and impact overall health."
R1, Female

3.2.2 The Respondents' views about their routine practices

Respondents described the steps taken to assess patients' nutritional needs, such as evaluating weight and height to calculate nutrient requirements. Based on these assessments, customized meal plans are developed and documented. These plans are then shared with the hospital restaurant or patient assistants to ensure meals align with the nutritional goals for each patient.

"We usually assess the patient's weight and height for assessing nutrient needs then we design a meal plan written on paper then shared to the hospital restaurant to be prepared".
R3, Male

As shown in figure 2, respondents mentioned the role of each one among nutritionists, social workers, and restaurant staff and how they collaborate.

3.2.3 Expectations and Needs for the Dietary Management System.

Respondents expressed a need for the dietary management system to provide clear and standardized guidelines on portion sizes and serving sizes, which can be easily communicated to hospital restaurant staff and patient assistants. They expect the system to facilitate accurate meal preparation, helping patients adhere to their dietary requirements and supporting better blood sugar control and overall health outcomes.

"We need a dietary management system that clearly defines portion sizes and serving guidelines. It should be easy for hospital kitchen staff and patient assistants to follow, ensuring that meals meet patients' dietary needs and support their blood sugar control and overall health." R6, Male

Respondent is expecting this dietary management system to be integrated effectively with the electronic medical record (EMR) system, enabling real-time access to patient data for efficient and personalized meal planning. This integration, combined with the system's speed, will allow staff to quickly retrieve dietary guidelines, facilitating timely meal preparation.

"The dietary management system must integrate with EMR for real-time patient data, enabling quick meal plan customization, prompt guideline retrieval, and a user-friendly interface for all staff to navigate easily". R2, Male

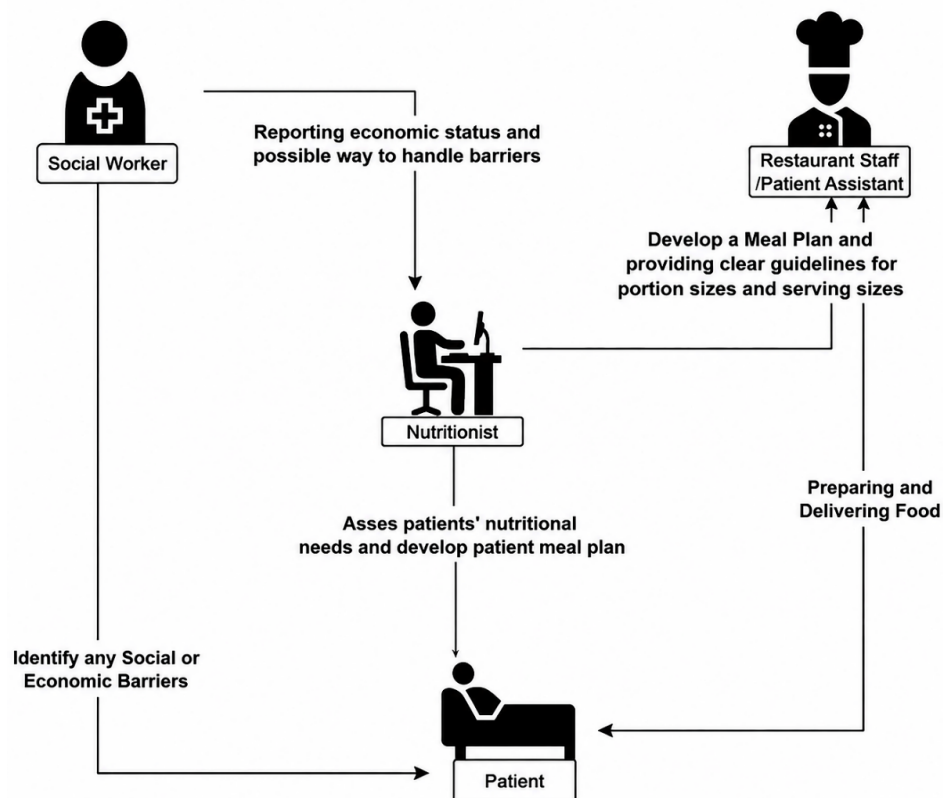


Fig. 2. Use-case diagram showing roles and collaboration among nutritionists, social workers and restaurant staff.

3.3 System architecture

The three qualitative themes above directly informed the system design: the described nutritionist-social worker-restaurant staff workflow (Figure 2) shaped the role-based access and hand-off structure built into the system; the expressed need for standardized, easily communicated portion sizes shaped the automated, glycaemic-index-based meal recommendation logic described below; and participants' emphasis on individualised assessment shaped the use of patient-specific inputs (weight, height, blood sugar, activity level) as the basis for each recommendation.

The system architecture provides an overview of the personalized digital nutrition support system prototype and its components, illustrated in Figure 3 below. The food recommendation process initiates when a nutritionist inputs the patient's weight, height, blood sugar levels, and activity level into the system. The glycaemia readings module collector receives these inputs and employs the Naïve Bayes algorithm module to identify a suitable food item based on its glycemic index and glycemic load. This recommended food item is then sent to either the restaurant staff or patient assistant for preparation and consumption, assisting the user in managing their blood sugar levels.

3.4 Calorie requirement determination.

To calculate the calorie requirement using the Harris–Benedict equation, we need to know the person's gender, age, height, weight, and activity level. Within the system, the basal metabolic rate is first computed from these variables and then multiplied by an activity factor to obtain the total daily energy requirement, which in turn bounds the calorie content of the meal plan generated [25].

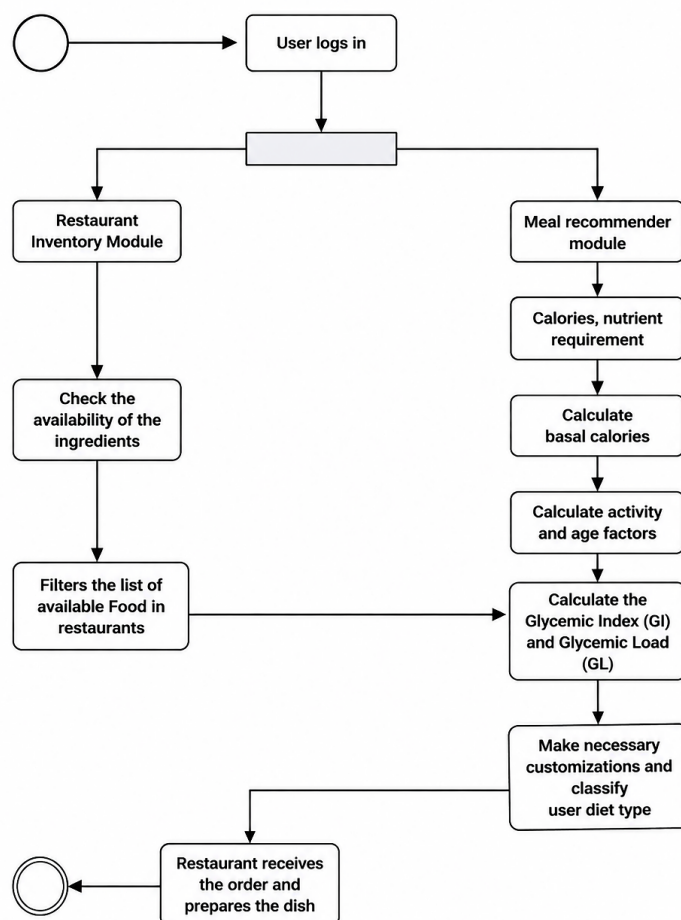


Fig. 3. Activity flow diagram of the implemented meal recommender system.

3.5 System Implementation

The web-based meal recommender system provides a comprehensive solution for Nutritionists, Restaurant Staff, and Social Workers to address the dietary needs and social concerns of their respective clients. By leveraging user profiles, a vast meal database, and advanced recommendation algorithms, the system promotes healthy eating habits, facilitates meal planning, and ensures that individuals receive tailored meal suggestions that align with their unique requirements.

The web-based system developed in PHP is designed to provide meal plan recommendations for diabetic inpatients. The implementation involves several components and functionalities to ensure the system operates effectively.

The system consists of three main components.

- **Client-side program:** This is the part of the system that users interact with. It is responsible for displaying the user interface and processing user input. The client-side program is typically written in a language like HTML or XML.
- **Web application server:** This is the part of the system that handles requests from users and generates responses. It is responsible for storing data, processing requests, and generating responses. The web application server was implemented using PHP, a widely used open-source scripting language for web development.
- **Database server:** This is the part of the system that stores data. It is responsible for storing and retrieving data as needed by the web application server. The database server was implemented using MySQL, an open-source relational database management system (DBMS), rather than a programming language, used here to store and retrieve patient, meal, and nutrition data.

The three components of the Meal Recommender system are all interconnected. The client-side program sends requests to the web application server, which then sends requests to the database server. The database server then sends the requested data back to the web application server, which then sends it back to the client-side program. This process happens very quickly, so users do not notice any lag or delay.

3.6 System Testing

The web-based system prototype was implemented using HTML for the client-side interface, PHP for the application server and MySQL for the database. This implementation approach allowed for continuous iterations, or repeated changes, in the different phases of development. The prototype was tested continuously to check for performance issues and bugs. Functional testing was also conducted to confirm that the prototype met the specified functional requirements.

The testing process comprised three activities carried out iteratively across the Agile development cycle, described below:

- **Performance testing:** the development team repeatedly loaded the prototype with simulated concurrent user sessions, representing nutritionists, restaurant staff, and social workers accessing the system at the same time, to check response times and system stability.
- **Bug testing:** the development team systematically exercised each module of the prototype after every development iteration, logging any errors encountered (for example, incorrect meal calculations or input-handling faults) and resolving them before the next iteration began.
- **Functional testing:** the development team verified, module by module, that the prototype correctly performed each function specified in the requirements, such as correctly calculating calorie needs using the Harris-Benedict equation and correctly generating a meal recommendation from a given set of patient inputs.

In addition to performance, bug, and functional testing, a usability and validation test was conducted: a questionnaire was created using Google Forms and distributed to the 11 study participants via WhatsApp to assess the prototype's usability and the validity of its recommendations; results are reported under Usability Test Results in the Results section.

By conducting continuous testing, the developers were able to identify and fix any problems with the prototype early in the development process. This helped to ensure that the final system was of high quality and met the needs of the users.

3.7 Users interface

The meal recommender system incorporates user interfaces tailored for nutritionists, restaurant staff, and social workers, ensuring efficient communication and streamlined workflows.

3.7.1 Nutritionist interface

The interface provides comprehensive dietary information, allowing them to input clients' specific measures including weight, height, blood sugar level, health conditions, and goals. The system then generates personalized meal recommendations, highlighting nutritional values and reports the meal plan generated to the chef restaurant.

Registered individuals can be accessed through a patient's menu, where all their relevant information will be displayed. If any errors are detected by the Nutritionists who facilitate the registration, they can double-click on the item's name to edit and update the item module.

The registered food Layout.

Food items that have been registered can be accessed through a menu. All relevant information about the food items will be displayed. If any errors are detected by the restaurant staff who facilitates the registration, they can double-click on the item's name to edit and update the item module, this process allows the restaurant staff to keep the registered food items up-to-date and to correct any errors that may have been made.

CLIENT INFORMATION
 Displays the client's personal and health details

EDIT CONTROL
 Click to edit the meal plan

Set Meal Plan of : NIYONTA Evariste
Monday 12-06-2023

Age: 23
Height: 169 cm
Weight: 89 Kg
Activity: Medium
BMR: 1941.16 Kcal
BMI: 31.2 kg/m²
B.Sugar: 210 mg/dL
Date: 03-06-2023

Parts of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
When you wake up	Water	Water	Water	Water	Water	Water	Water
Breakfast	Green soup + fish(Thomson) + Brown Bread	Quinoa + Peas + Carrot + Onions	1 Egg Boiled + Amaranth Seeds Porridge	Whole Oats + Egg (Omolet)	Boiled Soup of meat + Brown Bread	1 Egg Boiled + Amaranth Seeds Porridge	Omolet cooked with + Cabbage
09h00 - 11h00	Water	Water	Water	Water	Water	Water	Water
Lunch	Green Banana + Chicken + Beans Carrot + Olive + Onions + Poivron + Tomato	Sweet Potatoes + Peas + Cauliflower Carrot + Olive + Onions + Poivron + Tomato	Boiled Cassava + fresh beans + cauliflower + spinach + tomato + Garlic + Small fishes	Kidney Beans + Broccoli + Carrot + Olive + Onions + Poivron + Tomato + Plantain Boiled	Carrot + Chicken + Taro + Onions + Peas Boiled + Poivron + Tomato	Carrot + Beef + Olive + Onions + Poivron + Tomato + Brown Rice	Carrot + Fish + Olive + Onions + Poivron + Tomato + Green Banana
15h00 - 17h00	Papaye Cinnamon Tea	Apple Fruit	Papaye Cinnamon Tea	Passion - Apple Fruit	1 Apple Cinnamon Tea	1 Orange	Guava Cinnamon Tea
It's Night	Peas + egg-plant + tomato + avocado + Quinoa	Broccoli + fresh beans + carrots + tomatoes 1 Egg	Soup of mushroom + Brown Bread	Amaranth + Egg Plant + Carrot, Tomato, Onions + Peas + Boiled Oats	Zucchini + eggplant + carrots + tomatoes + onions + Plantain	Green banana + fresh beans + cauliflower + spinach + Tomato + Garlic + beans	Cassava + Spinach + tomatoes + Bell pepper onions + Garlic + Peas

Share to email
 Print meal plan

GENERATED MEAL PLAN PANEL
 Displays the customized meal plan

3.7.2 Restaurant Staff Interface.

The meal recommender system also has a user interface that allows restaurant staff to input the menu items that are available at their restaurant. The system should then show a list of meal recommendations based on the restaurant's menu and the client's dietary restrictions that have been sent by the nutritionist.

3.7.3 Social worker interface.

Social workers interact with an interface that enables them to input clients' socioeconomic backgrounds and reporting options. The system then processes this information to suggest affordable and accessible meal options, considering the clients' specific circumstances.

3.8 Usability and validation results

As described under System Testing in the Methods section, a usability and validation questionnaire was distributed to the 11 study participants; 10 participants responded, and all participants were able to open the link to the system.

All the participants confirmed that the prototype system provides personalized meal recommendations for diabetic inpatients.

All the participants confirmed that the prototype system helps in identifying food triggers that lead to blood glucose fluctuations in diabetic inpatients.

In addition, 60% agreed that the prototype system offers potential cost savings by reducing the need for manual monitoring and dietary interventions. This perception was not accompanied by any economic measurement and should therefore be read as a user expectation rather than as an evaluated outcome.

4 Discussion

In this study of creating a web-based model prototype, we employed the Agile development methodology to complete each stage necessary to develop the prototype [26]. These stages, delivered in iterative cycles rather than in a single linear pass, include defining the system requirements and specifications, designing the system, and creating the prototype [26].

The meal recommender prototype was developed using a machine learning algorithm that considers the patient's age, gender, weight, height, body mass index (BMI), nutritional requirements and food glycemic index. Nonetheless, Faiz et al. have employed an integrated ontology-based methodology that merges information from diverse domains, aiming to produce dietary and exercise recommendations tailored for individuals with diabetes [27]. The algorithm was trained using a dataset of 100 meals, and it was validated using a sample of 30 diabetic patients. In contrast, some studies relied on country-specific food composition table databases, such as the Malaysian one which implemented an ontological knowledge domain model and applied case-based reasoning. This approach helped them identify suitable menus by considering factors like energy requirements, body mass index, religion, and race [28].

The application system designed will help to address the issue of malnutrition among diabetic patients. Malnutrition is a prevalent problem among diabetic patients due to their specific dietary requirements and restrictions [29]. By using a meal recommender system, nutritionists can ensure that patients receive the necessary nutrients and food groups in their diet, reducing the risk of malnutrition and its associated complications [30].

Furthermore, the development of a meal recommender system can save nutritionists time and effort in creating personalized meal plans, enabling them to focus on other important aspects of patient care [31]. The system can also help streamline the meal planning process, ensuring that patients receive their meals promptly and efficiently [32].

Economic implications. The economic feasibility of deploying this system in Rwandan hospitals warrants explicit consideration, since it was not measured in the present study. On the cost side, the prototype was deliberately built on open-source components (PHP and MySQL) and runs on computers already present in the participating hospitals, so the principal incremental costs are not licensing but implementation: server hosting or shared use of existing hospital infrastructure, network connectivity in ward and kitchen areas, devices for restaurant staff, initial training, and continuing technical maintenance and curation of the food database. On the benefit side, 60% of participants anticipated cost savings through reduced manual monitoring, and the plausible offsets are nutritionist time released for clinical tasks, fewer inappropriate or wasted meal trays, and, if glycemic control improves, a shorter length of stay, which has already been shown to be associated with malnutrition risk in this same patient population [33]. These offsets remain hypothetical. Systematic reviews of health service delivery interventions in low- and middle-income countries and of digital health interventions more broadly report cost-effectiveness estimates that vary widely with implementation context, and both caution against assuming favourable economics in the absence of setting-specific data [37] [38]. A pragmatic way forward would be to nest a costing study within the pilot deployment proposed below, capturing set-up and recurrent costs alongside clinical outcomes, and to align this with the national digital health investment framework so that the system is costed as an addition to existing health information infrastructure rather than as a stand-alone platform [43].

4.1 Advantages of the application

The system utilized by nutritionists, restaurant staff, and social workers to connect and collaborate offers several advantages for improving the lives of hospitalized diabetic patients. Firstly, it enables efficient communication and coordination between these key stakeholders, ensuring that everyone is on the same page regarding the dietary needs and restrictions of the patients. By reporting the available food in stores, the system allows nutritionists to make informed decisions while creating personalized meal plans for the patients, considering their specific nutritional requirements. This not only enhances the quality and appropriateness of the meals but also helps in managing blood sugar levels and promoting overall health. Additionally, the system streamlines the process of generating meal plans, reducing the time and effort required by nutritionists and enabling them to focus on other critical aspects of patient care. By facilitating effective collaboration and providing accurate information, this system plays a vital role in improving the overall well-being and quality of life for diabetic patients during their hospitalization.

The main aim of this system is to help users to get a proper diet plan to maintain his/her health routine in diabetes. The user enters his/her personal details such as Age, Weight, Height, Glucose level, Contact and Location (Hospital and Department), thereby creating his/her profile. Our System can calculate his BMI and BMR using their details and accordingly, the diet plan suggests to the user.

4.2 Limitations of the application

While the system described above offers numerous advantages, it is important to acknowledge its limitations, one limitation is the reliance on accurate and up-to-date information regarding the available food in stores. If the system does not receive timely updates or encounters inaccuracies in the reporting of food availability, it may lead to errors in meal planning and compromise the effectiveness of the system. Additionally, the system's effectiveness heavily relies on the collaboration and communication between nutritionists, restaurant staff, and social workers. In situations where there is a lack of cooperation or a breakdown in communication, the system's ability to generate appropriate meal plans and improve the overall life of hospitalized diabetic patients may be hindered. Furthermore, the system may not be fully customizable to accommodate individual patient preferences and dietary restrictions. This could limit its ability to provide personalized and tailored meal plans for each patient. It is crucial to address these limitations through continuous monitoring, feedback, and updates to ensure the system's optimal performance and maximize its benefits for diabetic patients.

Several further limitations should be noted. First, the qualitative evaluation involved a small sample of 11 hospital staff drawn from two referral hospitals in Kigali; this limits the transferability of the findings to other facilities, including lower-level district or rural hospitals with different staffing and resource levels. Although this number falls within the range at which thematic saturation is commonly reached for a narrowly defined qualitative objective [42], it precludes any subgroup comparison, for example between cadres or between the two hospitals, and the sample did not include ward nurses or attending physicians. Second, the system's nutrient calculations depend on the Tanzania Food Composition Table rather than a Rwanda-specific database; food composition can vary by growing conditions, preparation method, and region, and cross-country food composition tables carry documented limitations in sub-Saharan Africa, including outdated source data and gaps for local dishes [36]. Third, the present evaluation assessed prototype usability and validation from the perspective of hospital staff only; it did not include patient-level testing or measurement of clinical outcomes such as glycemic control, so the system's effect on actual patient health has not yet been demonstrated. Fourth, real-world deployment in Rwandan hospitals would need to contend with practical constraints not captured in this prototype evaluation, including intermittent internet connectivity, device availability for restaurant and ward staff, staff turnover and retraining needs, and the ongoing accuracy of food-stock data described above. Finally, the cost-effectiveness of deploying and maintaining the system at scale was not assessed in this study; digital health interventions in low-resource hospital settings can incur non-trivial costs for hardware, connectivity, training, and maintenance, and evidence from other low- and middle-income country health-technology evaluations suggests that cost-effectiveness should be assessed explicitly before scale-up, rather than assumed [37,38]. Addressing these limitations, particularly through patient-level clinical validation and a formal cost-effectiveness analysis, is an important direction for future work.

4.3 Future Work

Future work will aim to integrate our project web-based meal recommender system with an electronic health record (EHR). In the future, this system will enable health providers and hospitalized patients, whether they have diabetes or not, to effortlessly create meal plans that can enhance their health by incorporating diet, physical activity, medication, and potentially other factors.

Beyond integration with the electronic health record, the priority for future work is clinical validation at patient level. The present evaluation established that the intended users regard the prototype as usable and its recommendations as plausible, but usability is not efficacy. A two-stage validation is therefore proposed. The first stage would be a single-arm pilot among hospitalized adults with type 2 diabetes at the two study sites, in which the system generates the meal plan actually served and outcomes are captured prospectively: fasting and post-prandial capillary glucose, glycaemic variability, the proportion of each prescribed meal consumed, and length of stay. The second stage would be a randomized controlled trial comparing system-generated meal planning with standard nutritionist-led planning, powered on change in HbA1c, with

patient-reported acceptability and dietary adherence as secondary outcomes. HbA1c is the outcome on which comparable mHealth diabetes interventions in Africa and self-management interventions in sub-Saharan Africa have been assessed and pooled, so adopting it would allow the system to be compared directly with the existing evidence base [41,44]. Reported reductions in HbA1c and glycaemic variability following comparable food recommender systems elsewhere offer a reasonable basis for the effect-size assumptions of such a trial [39]. The costing study described above should be nested within the second stage.

5 Conclusion

The study developed a meal recommender system to help nutritionists generate meal plans for diabetic patients. The system was designed to include local foods and consider the patients' physical activity level and food glycemic index. The system's strength is its ability to estimate users' physical activity level to suggest the best meal according to their calorie requirements.

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Conflict of interest

The authors declare that they have no conflict of interest.

Author's contribution

PK made substantial contributions to the primary study by collecting data, conducting analyses, and drafting the manuscript. The supervision and direction of the project were carried out by OG, JA, and EM. While JR contributed to the review of the manuscript.

References

- [1] Bilbeisi E, Afifi E, Taleb M, Qidra E. Malnutrition and Their Association with Diabetes Complications Among Hospitalized Type 2 Diabetes Patients in Gaza Strip , Palestine. *Austin J Nutr Food Sci*. 2019;
- [2] Barker LA, Gout BS, Crowe TC. Hospital malnutrition: Prevalence, identification and impact on patients and the healthcare system. *Int J Environ Res Public Health* [Internet]. 2011;8:514–27. Available from: doi:10.3390/ijerph8020514
- [3] WHO. Malnutrition. 2021;2020–2. Available from: <https://www.who.int/news-room/questions-and-answers/item/malnutrition>
- [4] WHO. Diet, nutrition and the prevention of chronic diseases. *World Heal Organ - Tech Rep Ser* [Internet]. 2003; Available from: <https://apps.who.int/iris/handle/10665/42665>
- [5] Schmidt SK, Hemmestad L, Macdonald CS, Langberg H, Valentiner LS. Motivation and barriers to maintaining lifestyle changes in patients with type 2 diabetes after an intensive lifestyle intervention (The U-TURN trial): A longitudinal qualitative study. *Int J Environ Res Public Health* [Internet]. 2020;17:1–16. Available from: doi:10.3390/ijerph17207454
- [6] Sowah RA, Bampoe-Addo AA, Armoo SK, Saalia FK, Gatsi F, Sarkodie-Mensah B. Design and Development of Diabetes Management System Using Machine Learning. *Int J Telemed Appl* [Internet]. 2020;2020. Available from: doi:10.1155/2020/8870141
- [7] Cheung KL, Durusu D, Sui X, de Vries H. How recommender systems could support and enhance computer-tailored digital health programs: A scoping review. *Digit Heal* [Internet]. 2019;5:1–19. Available from: doi:10.1177/2055207618824727
- [8] Alian S, Li J, Pandey V. A Personalized Recommendation System to Support Diabetes Self-Management for American Indians. *IEEE Access*. 2018;6:73041–51.

- [9] Bednarczuk B, Czekajło-Kozłowska A. Role of Nutritional Support Provided By Qualified Dietitians in the Prevention and Treatment of Non-Communicable Diseases. *Rocz Panstw Zakł Hig / Ann Natl Inst Hyg* [Internet]. 2019;70:235–41. Available from: doi:10.32394/rpzh.2019.0080
- [10] Eide HD, Halvorsen K, Almendingen K. Barriers to nutritional care for the undernourished hospitalised elderly: Perspectives of nurses. *J Clin Nurs* [Internet]. 2015;24:696–706. Available from: doi:10.1111/jocn.12562%0A
- [11] Reber E, Gomes F, Vasiloglou MF, Schuetz P, Stanga Z. Nutritional risk screening and assessment. *J Clin Med* [Internet]. 2019;8:1–19. Available from: doi:10.3390/jcm8071065
- [12] Nursing times. Assisting patients with eating and drinking to prevent malnutrition 09. 2017;1–9. Available from: <https://www.nursingtimes.net/clinical-archive/nutrition/assisting-patients-with-eating-and-drinking-to-prevent-malnutrition-09-10-2017/>
- [13] Eze NM, Maduabum FO, Onyeke NG, Anyaegunam NJ, Ayogu CA, Ezeanwu BA, et al. Awareness of food nutritive value and eating practices among Nigerian bank workers. *Med (United States)* [Internet]. 2017;96:1–6. Available from: doi:10.1097/MD.00000000000006283
- [14] Abrahams M, Matusheski N V. Personalised nutrition technologies: a new paradigm for dietetic practice and training in a digital transformation era. *J Hum Nutr Diet* [Internet]. 2020;33:295–8. Available from: doi:10.1111/jhn.12746
- [15] Ordoas J. Personalised nutrition and health [Internet]. 2018. Available from: doi:10.1136/bmj.k2173
- [16] Chaudharya N, Kumarb V, Sangwanc P, Pantd NC, Saxenae A, Joshif S, et al. Personalized Nutrition and - Omics. 2020; Available from: isbn:9780081005965
- [17] Sangeetha Shyam, Ke Xin Lee, Angeline Shu Wei Tan TAK. Effect of Personalized Nutrition on Dietary, Physical Activity, and Health Outcomes A Systematic Review of Randomized Trials Enhanced Reader.pdf.
- [18] Gibney M, Walsh M, Goosens J. Chapter 5.1 Personalized Nutrition: Paving the way to better population health. *Good Nutr Perspect 21st Century* [Internet]. 2016;235–48. Available from: doi:10.1159/000452389
- [19] Roberts S, Hopper Z, Chaboyer W, Gonzalez R, Banks M, Desbrow B, et al. Engaging hospitalised patients in their nutrition care using technology: development of the NUTRI-TEC intervention. *BMC Health Serv Res* [Internet]. 2020;20:1–11. Available from: doi:10.1186/s12913-020-5017-x
- [20] Naithani S, Whelan K, Thomas J, Gulliford MC, Morgan M. Hospital inpatients' experiences of access to food: A qualitative interview and observational study. *Heal Expect* [Internet]. 2008;11:294–303. Available from: doi:10.1111/j.1369-7625.2008.00495.x
- [21] Osman NS, Nor N, Sharif MS, Bariah S, Hamid A, Rahamat S. Hospital Food Service Strategies to Improve Food Intakes among Inpatients : A Systematic Review. 2021;1–26. Available from: doi:10.3390/nu13103649
- [22] Food and Agriculture Organization (FAO). Food composition tables for Tanzania. 2022;2008:8129.
- [23] Kane DW, Hohman MM, Cerami EG, McCormick MW, Kuhlman KF, Byrd JA. Agile methods in biomedical software development : a multi-site experience report. 2006;12:1–12. Available from: doi:10.1186/1471-2105-7-273
- [24] Philipp Mayring. Qualitative content analysis [Internet]. 2000. Available from: <https://www.qualitative-research.net/index.php/fqs/article/view/1089/2386>
- [25] Hsu PH, Lee CH, Kuo LK, Kung YC, Chen WJ, Tzeng MS. Determination of the energy requirements in mechanically ventilated critically ill elderly patients in different BMI groups using the Harris–Benedict equation. *J Formos Med Assoc* [Internet]. 2018;117:301–7. Available from: <https://doi.org/10.1016/j.jfma.2017.12.010>
- [26] Guerrero-Ulloa G, Rodríguez-Domínguez C, Hornos MJ. Agile Methodologies Applied to the Development of Internet of Things (IoT)-Based Systems: A Review. *Sensors* [Internet]. 2023;23. Available from: <https://doi.org/10.3390/s23020790>
- [27] Faiz I, Mukhtar H, Khan S. An integrated approach of diet and exercise recommendations for diabetes patients. 2014 IEEE 16th Int Conf e-Health Networking, Appl Serv Heal 2014 [Internet]. 2014;537–42. Available from: doi:10.1109/HealthCom.2014.7001899
- [28] Arens-Volland A, Gateau B, Naudet Y. Semantic Modeling for Personalized Dietary Recommendation. *Proc - 13th Int Work Semant Soc Media Adapt Pers SMAP 2018* [Internet]. 2018;93–8. Available from: doi:10.1007/978-3-319-70682-5_22
- [29] Ahmed I, Kaifi HM, Tahir H, Javed A. Malnutrition among patients with Type-2 Diabetes Mellitus. *Pakistan J Med Sci* [Internet]. 2023;39:64–9. Available from: doi:10.12669/pjms.39.1.5485
- [30] Yera R, Alzahrani AA, Martínez L, Rodríguez RM. A Systematic Review on Food Recommender Systems for Diabetic Patients. *Int J Environ Res Public Health* [Internet]. 2023;20. Available from: doi:10.3390/ijerph20054248
- [31] Yera Toledo R, Alzahrani AA, Martinez L. A food recommender system considering nutritional information and user preferences. *IEEE Access* [Internet]. 2019;7:96695–711. Available from: doi:10.1109/ACCESS.2017
- [32] Norouzi S, Ghalibaf AK, Sistani S, Banazadeh V, Keykhaei F, Zareishargh P, et al. A mobile application for managing diabetic patients' nutrition: A food recommender system. *Arch Iran Med* [Internet]. 2018;21:466–72. Available from: issn:17353947

- [33] Kwizera P, Niyomwungeri R, Gatera O, Adu-Amoah HG, Ahishakiye J. Malnutrition risk among hospitalized patients with type 2 diabetes mellitus and its association with hospital length. *Public Health Challenges*. 2024;3(4):e70011. Available from: <https://doi.org/10.1002/puh2.70011>
- [34] Aboye GT, Gebremichael EH, Simegn GL, Aerts JM. User-centered diabetes self-management app (DiabAid Nexus) in sub-Saharan Africa: development and usability study. *J Med Internet Res*. 2026;28:e87110. Available from: <https://www.jmir.org/2026/1/e87110>
- [35] Aovare P, Beune E, Laar A, Moens N, Moll van Charante EP, Agyemang C. User experiences with a mobile health app for self-management of diabetes and hypertension in Ghana: a qualitative study. *Ann Med*. 2025;57(1):2517395. Available from: <https://doi.org/10.1080/07853890.2025.2517395>
- [36] de Bruyn J, Ferguson E, Allman-Farinelli M, Darnton-Hill I, Maulaga W, Msuya J, Alders R. Food composition tables in resource-poor settings: exploring current limitations and opportunities, with a focus on animal-source foods in sub-Saharan Africa. *Br J Nutr*. 2016;116(10):1709-1719. Available from: <https://doi.org/10.1017/S0007114516003706>
- [37] Watson SI, Sahota H, Taylor CA, Chen YF, Lilford RJ. Cost-effectiveness of health care service delivery interventions in low and middle income countries: a systematic review. *Global Health Res Policy*. 2018;3:17. Available from: <https://doi.org/10.1186/s41256-018-0073-z>
- [38] Gentili A, Failla G, Melnyk A, Puleo V, Di Tanna GL, Ricciardi W, Cascini F. The cost-effectiveness of digital health interventions: a systematic review of the literature. *Front Public Health*. 2022;10:787135. Available from: <https://doi.org/10.3389/fpubh.2022.787135>
- [39] Ahmed E, Oumer M, Hassan M. Diabetes-focused food recommender system (DFRS) to enabling digital health. *PLOS Digit Health*. 2025;4(2):e0000530. Available from: <https://doi.org/10.1371/journal.pdig.0000530>
- [40] Ageru TA, Le CN, Wattanapisit A, Woticha EW, Truong NT, Stanikzai MH, et al. Diabetes self-care intervention strategies and their effectiveness in Sub-Saharan Africa: a systematic review. *PLoS One*. 2024;19(10):e0305860. Available from: <https://doi.org/10.1371/journal.pone.0305860>
- [41] Dike FO, Mutabazi JC, Musa E, Ubani BC, Isa AS, Ezeude CM, et al. Implementation and impact of mHealth in the management of diabetes mellitus in Africa: a systematic review and meta-analysis. *PLOS Digit Health*. 2025;4(4):e0000776. Available from: <https://doi.org/10.1371/journal.pdig.0000776>
- [42] Hennink M, Kaiser BN. Sample sizes for saturation in qualitative research: a systematic review of empirical tests. *Soc Sci Med*. 2022;292:114523. Available from: <https://doi.org/10.1016/j.socscimed.2021.114523>
- [43] Republic of Rwanda, Ministry of Health. National Digital Health Strategic Plan 2018-2023. Kigali: Ministry of Health; 2018. Available from: https://extranet.who.int/countryplanningcycles/sites/default/files/public_file_rep/RWA_Rwanda_Digital-Health-Strategy_2018-2023.Pdf
- [44] Carter N, Nalbant G, Chahal P, Chattopadhyay K. Effectiveness and safety of self-management interventions for improving glycemic control and health-related quality of life among adults with type 2 diabetes mellitus in sub-Saharan Africa: a systematic review and meta-analysis. *JBIM Evid Synth*. 2024;22(9):1715-88. Available from: <https://doi.org/10.11124/JBIES-23-00273>