DESIGN, DEVELOPMENT AND VALIDATION OF A SMARTPHONE APPLICATION FOR DIETARY ASSESSMENT

By

SUBEG SINGH MAHAL

Department of Bioresource Engineering

McGill University, Montréal

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Dedication

This thesis is dedicated to my late grandfather 'S. Ajaib Singh'

ABSTRACT

The development agenda continues to prioritize food security and nutrition around the world. A better understanding of dietary patterns, diet quality, and diet diversity can improve the intervention programs, especially in developing countries, by identifying and quantifying typical diets. Traditionally, the food consumption data has been collected by food frequency questionnaires, food records, and 24-hour dietary recalls via paper questionnaires administered by the interviewer. However, limitations in each of these traditional methods affect the data collection, and ultimately skew the conclusions. As smartphones proliferate around the world, their applications offer an increasingly viable alternative to traditional dietary data collection methods. In the first phase of this study, ‘Diet DQ Tracker’, a smartphone application was developed for android and iOS devices to collect dietary data for MDD-W, IYCF-MDD, and HDDS. A robust database structured in accordance with the dietary guidelines of these diet diversity indicators was developed and linked with the application, assisting respondents to record dietary intake from a pre-defined list of 8777 food items and beverages. In the second phase, the relative validity, feasibility, and acceptability of ‘Diet DQ Tracker’ with reference to interviewer-administered 24-hour dietary recall was assessed. This phase collected and compared the dietary data from both methodologies, and then administered a feedback survey to gauge the user preferences. The diet diversity scores derived from both methodologies did not demonstrate any significant differences at the group level, indicating a satisfactory level of agreement. Overall, the performance of ‘Diet DQ Tracker’ was highly satisfactory. The application being more convenient, less time-consuming, easy to use, and portable was preferred by all respondents over the traditional 24-hour interviewer-administered dietary recall.

RÉSUMÉ

Le programme de développement continue de donner la priorité à la sécurité alimentaire et à la nutrition dans le monde. Une meilleure compréhension des habitudes alimentaires, de la qualité de l'alimentation et de la diversité de l'alimentation peut améliorer les programmes d'intervention, en particulier dans les pays en développement, en identifiant et en quantifiant les régimes alimentaires typiques. Traditionnellement, les données sur la consommation alimentaire ont été recueillies par des questionnaires de fréquence alimentaire, des registres alimentaires et des rappels alimentaires de 24 heures via des questionnaires papier administrés par l'enquêteur. Cependant, les limites de chacune de ces méthodes traditionnelles affectent la collecte de données et, en fin de compte, faussent les conclusions. Alors que les smartphones prolifèrent dans le monde, leurs applications offrent une alternative de plus en plus viable aux méthodes traditionnelles de collecte de données alimentaires. Dans la première phase de cette étude, "Diet DQ Tracker", une application pour smartphone a été développée pour les appareils Android et iOS afin de collecter des données alimentaires pour MDD-W, IYCF-MDD et HDDS. Une base de données robuste structurée conformément aux directives diététiques de ces indicateurs de diversité alimentaire a été développée et liée à l'application, aidant les répondants à enregistrer l'apport alimentaire à partir d'une liste prédéfinie de 8 777 aliments et boissons. Dans la deuxième phase, la validité relative, la faisabilité et l'acceptabilité de "Diet DQ Tracker" en référence au rappel alimentaire de 24 h administré par l'intervieweur ont été évaluées. Cette phase a collecté et comparé les données alimentaires des deux méthodologies, puis a administré une enquête de rétroaction pour évaluer les préférences des utilisateurs. Les scores de diversité alimentaire dérivés des deux méthodologies n'ont pas démontré de différences significatives au niveau du groupe, indiquant un niveau d'accord satisfaisant. Dans l'ensemble, les performances de "Diet DQ Tracker" ont été très satisfaisantes. L'application, plus pratique, moins chronophage, facile à utiliser et portable, a été préférée par tous les répondants à la méthodologie traditionnelle.

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Subeg Mahal

CONTRIBUTION OF AUTHORS

The contribution and role performed by the different authors are as follow:

Mr. Subeg Singh Mahal is the principal author of this work. He is the M.Sc. candidate student who planned the research, conducted the experiments, analysed the data, and wrote the manuscripts. **Dr. Michael Ngadi** is the research supervisor who supervised the candidate design and implementation of the experiments, provided scientific suggestions, and reviewed the manuscripts of the above-mentioned work. **Dr. Christopher Kucha** is a post-doctoral researcher who assisted in giving the guidance, monitored the candidate work, and helped in revising the manuscripts.

This thesis is manuscript-based in accordance with the guidelines presented by Graduate and Postdoctoral Studies of McGill University and consists of two research manuscripts (Chapter III and IV). Chapter I, II and V consists of the introduction, literature review and summary, respectively.

The manuscripts prepared for submission to food and bioprocess engineering-related journals are listed below:

1) Subeg Singh Mahal, Christopher Kucha, Michael Ngadi. "Augmenting Diet Diversity Assessment in Nutrition Sensitive Agriculture: Review paper"
2) Subeg Singh Mahal, Christopher Kucha, Michael Ngadi. "Design and Development of 'Diet DQ Tracker': A Smartphone application for Augmenting Dietary Assessment"
3) Subeg Singh Mahal, Christopher Kucha, Michael Ngadi. "Comparative Validity of the 'Diet DQ Tracker' Smartphone Application and 24-hour Dietary Recall Methods for Dietary Diversity Monitoring"

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NOMENCLATURE

AMPM	Automated multiple-pass method
CATI	Computer assisted telephone interviewing
CMS	Content management system
CSV	Comma-separated values
DD	Diet diversity
DDS	Diet diversity score
Diet ‘DQ’ Tracker	Diet ‘diversity quality’ tracker
DLW	Doubly labelled water
DQ	Diet quality
EHFP	Enhanced homestead food production
FAO	Food and agriculture organization
FCS	Food consumption score
FFQ	Food frequency questionnaire
FGI	Food group indicator
FNDDS	Food and nutrition database for dietary studies
HDDS	Household dietary diversity score
HEEE	Health, education, engineering and environmental
HFI	Household food insecurity
IFAD	International fund for agricultural development
IYCF	Infant and young child feeding practices
LIM	Nutrients to be limited
MDD	Minimum dietary diversity
MDD-W	Minimum dietary diversity for women
MMF	Minimum meal frequency
MPA	Mean probability of adequacy
NPNL	Non pregnant non lactating

PDA	Personal digital assistant
SAIN	Score of nutritional adequacy of individual foods
USDA	United states department of agriculture
WHO	World health organization

CHAPTER I

INTRODUCTION

1.1 Background

In the year 2019, 3 billion people worldwide lacked access to a nutritious diet (World Health Organization, 2021). The prevalence of undernourishment increased from 8.4 to 9.9% the following year, with one in every three people lacking access to adequate food (World Health Organization, 2021). The burden of food insecurity and malnutrition remains a global challenge (FAO, 2021). Diet quality has been often used to refer nutrient adequacy. A nutrition adequate diet is one that meets the energy and essential nutrient requirements of the individual. The rising problem of diet related chronic disease and obesity has shifted the definition of diet quality towards moderation, proportionality, and diet diversity. Diet diversity is one of the key features of diet quality. Regardless of the ample food production by contemporary intensive agricultural systems, monotonous diets that generally involve starchy staples remain a widespread challenge (Thompson et al., 2006). A single food item can not possess all vital minerals and proteins that satisfy the nutritional requirement of an individual; they are however present in diverse diets (Bridget & Wahlqvist, 1996). In a nutshell, diet diversity refers to the variety of different foods or food groups consumed by an individual or a household over a specific reference period (Ruel, Harris, et al., 2013). In both research and programmatic contexts, diet diversity indicators have been developed and used in many ways. Nevertheless, only a few simple indicators have been nurtured for population level use in resource-poor settings. These globally accepted indicators include Minimum Dietary Diversity for Women (MDD-W) (FAO, 2016), Minimum Dietary Diversity of Infant and Young Child Feeding Practices (IYCF-MDD) (World Health Organization, 2008), and Household Dietary Diversity Score (HDDS) (Swindale & Bilinsky, 2006).

Traditionally, dietary data for the diet diversity indicators is collected by written or orally reported methods, employing 24-hour (24-h) interviewer-administered questionnaires via telephone or in-person interviews (Ruel, Alderman, et al., 2013). The questionnaires can be list-based or open recall-based. In open recall, the interviewer simply probes the respondent to recall all food items consumed the previous day/night and places them in their respective food groups on the questionnaire. In the list-based method, the interviewer has a list of predefined food items for each group that is read to the respondent, and the respondent answers yes or no to the queries (Thompson & Subar, 2017). The interviewer-administered 24-h recall has a range of drawbacks, including recall bias, social-desirability bias, and cost-time constraints. Traditional methodology depends on respondent memory, attention, and persistence of the interviewer (Thompson et al., 2010). These factors contribute to under- or over-reporting of diets, resulting in deviated diet diversity scores (Bathalon et al., 2000). The complexity, respondent-interviewer burden, and resources required for an interviewer-administered 24-h recall have limited its implementation for dietary assessment at national or subnational levels, requiring frequent rounds of survey (Thompson et al., 2010). Therefore, to ensure effective and accurate dietary data collection at population level, it is critical to improve available dietary information by enhancing data collection and analysis methodologies.

The challenges associated with developing reliable dietary assessments have been extensively researched and debated (Subar et al., 2015). Dietary assessment tools need to be chosen based on the trade-offs between relative validity of different methodologies (Willett, 2012). Given the fact that personal digital assistants (PDAs), tape recorders, scan- and sensor-based technologies have all become obsolete, and all operations of web- or computer-based platforms/software can now be performed via smartphones, dietary evaluation via a smartphone-based application has a promising future (Bucher Della Torre et al., 2017). It has been suggested that employing mobile phone technologies may result in an improved assessment of dietary intake by overcoming inherent difficulties such as reliance on memory, time consumption, food portion measurement, trained or experienced interviewers, coding burden, food expertise, and other time-consuming chores (Willett, 2012). The use of mobile phones to measure dietary intake or improve the measurement of dietary intake has been explored in several studies (Ambrosini et al., 2018; Ashman et al., 2017; Boushey et al., 2017; Bucher Della Torre et al., 2017; Carter et al., 2013; Chae et al., 2011; Kong & Tan, 2012; Pendergast et al., 2017). Additionally, access to smartphones and the internet is growing exponentially throughout the world, across all sociodemographic and age groups (Touvier et al., 2010). Thus, the use of self-administered smartphone application to collect dietary data has become irrefutable, with the critical question being data's reliability and accuracy in comparison to traditional methodology.

1.2 Hypothesis

The hypothesis of this study is that developing a self-administered smartphone application for collecting dietary data will provide the opportunity to replace the traditional interviewer-administered methodology by overcoming its inherent limitations. The smartphone application will limit the effort and resources involved in data collection, analysis, and reporting while improving the data quality by reducing the misreporting errors.

1.3 Objectives

The overall objective of this research project was to develop and evaluate the performance of a smartphone application in dietary data collection in order to replace the traditional 24-h interviewer-administered recall methodology that is performed via pen and paper. The specific objectives to achieve the general objective were as follows:

1. Design and development of 'Diet DQ Tracker': a smartphone application for augmenting dietary assessment
    - i. To design and develop a user-friendly interface for collecting dietary data on MDD-W, IYCF-MDD, and HDDS
    - ii. To design and develop a robust food database that contains a list of thousands of foods and beverages, structured in accordance with the methodology used to calculate diet diversity scores
    - iii. To design and develop a Content Management System (CMS) to update the food database and manage the dietary data collected from users
2. To evaluate the relative validity of 'Diet DQ Tracker' with traditional methodology of interviewer-administered 24-h dietary recall
    - i. To compare and contrast the diet diversity scores achieved at group level via both methodologies
    - ii. To determine and analyze user acceptability, learnability, and preferability of 'Diet DQ Tracker' against interviewer-administered 24-h telephone recalls

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Micronutrient malnutrition affects one out of every seven people who do not have access to a high-energy, high-protein diet (Byerlee et al., 2008). An individual's physical health, psychological health, and working capacity are correlated with nutrition status. Maintaining good health in women of reproductive age is important not only for themselves, but also for the development, growth, and long-term health of their children. Foetal development, growth, brain development, and survival rate can all be improved by adequate nutrition during the first thousand days of a child's life (WHO, 2004). Child development is vulnerable between the age of 6 and 24 months, as it involves the transition in child feeding practices from exclusive breastfeeding to the consumption of complementary foods (Blackstone & Sanghvi, 2018). Low protein and carbohydrate diets would make women chronically malnourished mothers with a higher risk of infant mortality. Additionally, households may lack access to nutritionally adequate food during the times of food scarcity, resulting in decreased nutrient intake and diet diversity amongst all members of household (Rome, 1996). Children under the age of 5, and adults over the age of 60 are particularly sensitive to the negative effects of a poor diet (Cordero-Ahiman et al., 2021). Diets containing a little amount of fruits, vegetables, and animal origin products, put them at greater risk of micronutrient insufficiency (Bhandari et al., 2016). Many households worldwide, even those with the means to eat better, consume a diet high in carbohydrates and low in nutrient-rich foods, resulting in malnutrition (Schwei et al., 2017). Diet quality is a term that is often used for referring to nutrient adequacy. Diet diversity is one of the key features of diet quality (Ruel, Harris, et al., 2013). Diets that include a variety of food groups are critical for resisting malnutrition and foster better health in individuals and their offspring (Kennedy, Fanou-Fogny, et al., 2010).

Deficits and differences in nutrition consistency at individual and household level have been known for a long time. Around 2 billion people worldwide suffer from micronutrient deficiencies, a large portion of which is attributed to monotonous diets comprising of nutrient-deficit staple crops (Haas et al., 2016; Ritchie & Roser, 2017). As a result, the number of programmatic interventions that aim at improving diet diversity and nutrition has increased with time, as has the demand for indicators that track their impact and progress (Ruel, Alderman, et al., 2013). Although a variety of diet diversity indicators have been developed and implemented in both research and programmatic contexts, only a few indicators have been established for use at population level in resource-poor settings. These indicators include Minimum Dietary Diversity for Women (MDD-W), Minimum Dietary Diversity of Infant and Young Child Feeding Practices (IYCF-MDD), and Household Dietary Diversity Score (HDDS). MDD-W is a dichotomous indicator of whether women 15–49 years of age have consumed at least five out of ten defined food groups in last 24-hours. The ten defined food groups are: Grains, Roots, and Tubers; Pulses; Nuts and Seeds; Dairy; Meat, Poultry, Fish; Eggs; Dark green leafy vegetables; Other Vitamin A-rich fruits and vegetables; Other fruits; Other vegetables (FAO, 2016). Minimum dietary diversity (MDD) is one of the eight core indicators of Infant and Young Child Feeding Practices (IYCF) (Organization, 2008). MDD is defined as whether children aged between 6-23 months have consumed at least five out of eight defined food groups over the period of last 24-hours. The eight food groups are: Breast milk; Grains, roots and tubers; Legumes and nuts; Dairy products (milk, yogurt, cheese); Flesh foods (meat, fish, poultry and liver/organ meats); Eggs; Vitamin-A rich fruits and vegetables; and Other fruits and vegetables. The proportion of women 15–49 years of age and children 6-23 months of age, who achieve this threshold in a population, can be used as a proxy indicator for higher micronutrient adequacy, one important dimension of diet quality (FAO, 2016). On the other hand, HDDS is an attractive proxy indicator of diet diversity representing the entire household. It computes the diet diversity score by aggregating different food groups, out of twelve, consumed by all members of household over a 24-h period. Traditionally, diet diversity indicator's dietary data is collected by written or orally reported methods from a female member or household head by employing interviewer-administered questionnaires. These questionnaires can be open recall-based or list-based (Ruel, Harris, et al., 2013). In open recall, interviewer asks respondent to recall all food items/ beverages consumed in the last 24 hours and categorizes different constituents in their respective food groups on the questionnaire. Open recall-based questionnaires are usually administered by the multiple-pass method for 24-h recalls. The multiple-pass method consists of five steps that are followed in chronological order: quick listing of food, recalling forgotten foods, asking time and occasion of consumption, a thorough analysis of food composition, and ultimately a final review of all food items (Raper et al., 2004). On the other hand, in list-based method, the interviewer pre-defines a list of food items within each food group, and the respondent simply responds “yes” or “no” after listening the list. (Thompson & Subar, 2017).

However, the dietary data collection methodology used traditionally has a range of drawbacks, such as respondent and researcher burden (Touvier et al., 2011). The precision of 24-h recalls is hampered by memory and attention (Thompson et al., 2010). Additionally, the success of method depends on persistence of the interviewer. Interviewers need to identify food ingredients and categorize them into appropriate food groups. Hiring and training educated enumerators for conducting 24-h recalls is a costly process (Lamanna et al., 2019) that is challenging in resource-constrained environments. Moreover, it has been confirmed that using 24-h recalls as the sole method of diet assessment results in systemic negative bias, evolving a significant decrease in average daily energy and nutrient intake in rural populations (Poslusna et al., 2009). Respondents with unstructured eating habits and regular snacking are more likely to under-report their diets (Boushey et al., 2009). The feeding of 24-h recall questionnaires on a computer for analysis requires expertise and can be a time-consuming chore (Buzzard, 1998). The time and resources necessary for an interviewer-administered 24-h recall have limited its application for dietary assessment at national and subnational levels (Thompson et al., 2010).

To overcome these gaps, smartphone applications can be employed as a substitute for conventional interviewer-administered 24-h recalls (Wellard-Cole et al., 2019). According to Statista, there are currently 3.8 billion mobile users worldwide, which equates to 48.33 per cent of the global population. With time, smartphone capabilities have advanced, allowing them to link with the internet and run a complete operating system. Smartphone applications that enable users to track their food and beverage intake can be an easy and cost-effective way to conduct a dietary assessment (Wellard-Cole et al., 2019). Smartphones not only capture food entries faster than traditional methods but also collect real-time data and substantially reduce the researcher burden (Carter et al., 2013). The ‘Eat and Track’ (EaT) (Wellard-Cole et al., 2019), ‘My Meal Mate’ (Carter et al., 2013), ‘Electronic Dietary Intake Assessment’ (Steinhauserova & Borilova) (Rangan et al., 2015), ‘Easy Diet Diary’ (Ambrosini et al., 2018), and ‘Electronic Carnet Alimentaire’ (e-CA) (Bucher Della Torre et al., 2017) are few dietary tracking mobile applications that have been validated with 24-h dietary recall as a reference process. In three of these studies, the majority of participants were women (Ambrosini et al., 2018; Bucher Della Torre et al., 2017; Carter et al., 2013).

To the best of our knowledge, this is the first study that examines the existing methodologies of diet diversity indicator's and proposes the importance of replacing traditional methods with a smartphone application. The findings of this review paper helped us to identify and analyze the potential gaps in traditional methodologies. In the second stage, we propose that using a smartphone application for diet diversity indicators to capture and analyze data in real-time would help in overcoming the constraints of traditional methods, while improve the quality of data collection by increasing efficiency and limiting the misreporting errors.

2.2 Material and methods

2.2.1 Literature search

The goal of the literature search was to identify and assess the methodologies employed in studies that implement MDD-W, IYCF-MDD, and HDDS as diet diversity indicator for women, children, and households, respectively. Relevant literature includes the FAO report "Moving forward on choosing a standard operational indicator of women's dietary diversity" (Martin-Prével et al., 2015), the "Nutrition baseline survey summary report" (Kennedy et al., 2017) and systematic reviews of research on nutrition-sensitive agriculture that aided in the development of search strategy (Bird et al., 2019; Fiorella et al., 2016; Pandey et al., 2016; Verger et al., 2019). Keywords search in Scopus, MDPI Nutrients, Web of Science, PubMed, ScienceDirect, Agris (a literature search portal of the United Nations Food and Agriculture Organization), and Google Scholar was conducted in May 2021 to include peer-reviewed studies published in English. The keywords employed in the literature search were "women", "children", "households", "MDD-W", "MDD", "HDDS", "nutrition-sensitive interventions", "dietary diversity", "dietary quality", "food consumption", "food variety", "24-h dietary recall", and "food frequency questionnaire". This review considered all types of research designs related to diet diversity indicators, ranging from cross-sectional to cohort studies, as well as other impact evaluation or intervention studies.

2.2.2 Data screening and classification

All research papers were screened twice. In the initial screening stage, titles and abstracts were reviewed, and studies unrelated to the evaluation process were excluded. This was followed by a comprehensive text screening to ensure that studies met the second-stage eligibility criteria: studies that scrutinized, evaluated, associated, or validated either of diet diversity indicator amongst MDD-W, IYCF-MDD, and HDDS, with or without other household or individual diet diversity/ diet quality indicators, factors, or characteristics. The following data was tabulated to aid the full-text screening: (i) Research aim (purpose of the study); (ii) Study design (e.g. baseline survey of an intervention); (iii) Country (location of the study); (iv) Target audience (subject e.g. pregnant women (15-49 years)); (v) Dietary data collection methodology (e.g. 24-h dietary recall using the multiple-pass method); (vi) Sample size (number of participants involved e.g. N = 558); (vii) Dietary data type (e.g. Quantitative or Qualitative); (viii) Dietary data collection frequency (number of times dietary data collected e.g. once every year, for 3 years; (ix) Dietary data collection point (place where data was collected, e.g. household).

After screening, 80 studies were chosen to be included in this review. The applicability and methodology of these studies were assessed critically. To begin classification, studies were categorized according to methodology, whether the dietary data was gathered using an interviewer-administered recall (n = 78), self-administered recall (n = 2), or both (n = 0). The studies were further classified into four categories: 24-hour (24-h) dietary recall, 48-hour (48-h) dietary recall, 7-day (7-d) dietary recall, 30-day (30-d) dietary recall, and 1-year (1-y) dietary recall. Dietary data was classified as quantitative if the portion estimation of food was done by weighing scale, food photo atlas, or standard household utensils, including pots, plates, bowls, cups, or spoons. On the contrary, portion estimate was classed as semi-quantitative if it was performed solely to get an idea of the food quantity, else, it was categorized as qualitative. Dietary data collection frequency was classified as consecutive, if diets were recorded on sequential days, otherwise, it was classified as non-consecutive.

All critical assessment disagreements among the reviewing co-authors were settled through discussion.

TABLE 2.1: Context and methodology of diet diversity indicator studies

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Melby, 2020)	To establish relationship amongst agricultural food production diversity (FPD, Diet Diversity (DD), and household food insecurity (HFI)	Cross-sectional survey	Ecuador	Non-pregnant women (18-85 years)	24-h dietary recall Multiple pass	Quantitative	1 day	Household	N = 558
(Jones, 2018)	To establish association of farm level agricultural biodiversity with DD and DQ To assess the effect of market orientation on this association	Cross-sectional survey	Peru	Households with woman (18-49 years)	-24-h dietary recall questionnaire -Multimodule household survey questionnaire	Quantitative	Non-consecutive 2 days	Household	N = 100
(Zhang, 2020)	To investigate effect of DD on any type of fracture in adults	Secondary analysis of Cross-sectional survey	China	Adults (40 + years)	-24-h dietary recall questionnaire -Household food weight inventory	Quantitative	Consecutive 3 days	Household	N = 10,192 (4,795 Men; 5,397 Women)
(Nguyen, 2018)	To compare micronutrient adequacy between pregnant adolescent girls and women To check performance of WDDS-10 in predicting MPA To check performance of MDD-W in pregnant adolescent girls and women	Secondary analysis of Cross-sectional survey	Bangladesh	Pregnant women (18 + years)	-24-h dietary recall Multiple pass -24-h dietary recall -List-based questionnaire	Quantitative	Twice, same day	Household	N = 600

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Seiermann, 2021)	To check effect of dietary changes on women's health during Ramadan	Secondary analysis of repeated Cross-sectional survey	Bangladesh	Married women	-24-h dietary recall	Qualitative	Once every 2 months, for 5 years	Household	N = 852
(Sultana, 2019)	To assess DD and nutrition status of female residential students	Cross-sectional survey	Bangladesh	Women (18-26 years)	-24-h dietary recall Multiple pass	Quantitative	Consecutive 3 days	University	N = 160
(Bellon, 2016)	To investigate relationship of diversity of plant species raised and variety of foods purchased by women of rural households on DD under different market conditions	Cross-sectional survey	Benin	Households with women (15-49 years)	-24-h dietary recall -Semi-structured questionnaire - Food frequency questionnaire (FFQ)	Qualitative	-15 days (Farm diversity) -7 day (Market diversity) -1 day (Diet diversity)	Household	N = 652
(Diop, 2021)	To examine performance of 2 FGI indicators in predicting micronutrient adequacy	Baseline survey of an intervention	Burkina Faso	Pairs of children (24–59 months old) and women	-24-h dietary recall -Computer assisted personal interviewing	Quantitative	Non-consecutive 2 days	Household	N = 1,066
(Custodio, 2020)	To check association of MDD-W with socioeconomic, food security and purchasing practices	Secondary analysis of repeated Cross-sectional survey	Burkina Faso	Women (15-49 years)	-24-h dietary recall	Qualitative	Once every year, for 3 years	Household	N = 12,754

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Getacher et al., 2020)	To determine prevalence of MDD-W and associated factors among lactating mothers	Cross-sectional survey	Ethiopia	Women (15-49 years)	-24-h dietary recall	Qualitative	1 day	Household	N = 652
(Hanley-Cook et al., 2020)	To assess validity of List-based and Open recall-based methods with weighed food record for MDD-W	Cross-sectional survey	Cambodia Ethiopia Zambia	Women (15-49 years)	-24-h dietary recall -Weighed food records	Qualitative and Quantitative	1 day	Household	N = 1,337
(Girma et al., 2019)	To check nutrition and other factors that contribute to Low birth weight in newborns	Cross-sectional survey	Ethiopia	Women and Newborn infants	-24-h dietary recall -Questionnaires on socio-economic, medical, behavior, environment, and infant related factors	Qualitative	1 day	Health care facilities	N = 279
(Gyimah et al., 2021)	To understand factors contributing to DD in pregnant women	Longitudinal study	Ghana	Pregnant adolescents	-24-h dietary recall -Questionnaire on socio-demographic factors	Quantitative	3 days	Health care facilities	N = 416
(Agbozo et al., 2020)	To determine link between maternal food habits, antenatal care practices and the prevalence of anemia in the first, second, and third trimesters of pregnancy	Prospective study	Ghana	Women (15-49 years)	-24-h dietary recall -FFQ	Qualitative	1 day	Health care facilities	N = 415

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Saaka et al., 2021)	To determine the independent predictors of DD and their agreement in nutrition status of pregnant women	Cross-sectional survey	Ghana	Women (15-49 years)	-24-h dietary recall -7-d FFQ	Quantitative	1 day	Household	N = 423
(Ayensu et al., 2020)	To determine the prevalence of anemia and dietary micronutrient intakes in pregnant women	Cross-sectional survey	Ghana	Pregnant women (15-49 years)	24-h dietary recall -FFQ	Quantitative	Non-consecutive 3 days	Household	N = 379
(Bukari et al., 2021)	To examine diet quality and its association with household factors and gestational age	Cross-sectional survey	Ghana	Pregnant women (15-49 years)	24-h dietary recall -Questionnaires on socio-demographic characteristics	Qualitative	1 day	Health care facilities	N = 403
(Saaka et al., 2017)	To evaluate maternal dietary intake and its association with nutrition status	Cross-sectional survey	Ghana	Households with pregnant women (15-49 years)	-24-h dietary recall -FFQ	Qualitative	1 day	Household	N = 400
(Gupta et al., 2019)	To examine women's agricultural empowerment and iron in-sufficiency	Agriculture-nutrition study (Cross-sectional survey)	India	Non-pregnant Non-lactating (NPNL) women (15-49 years)	-24-h dietary recall -FFQ	Quantitative	1 day	Household	N = 960
(Nguyen et al., 2020)	To evaluate performance of list-based and quantitative open recall-based methods in predicting micronutrient adequacy	Secondary analysis of baseline survey	Bangladesh India	Pregnant women	-24-h dietary recall -Qualitative list-based questionnaire -Quantitative open-recall based on multiple pass method	Quantitative	1 day Repeated for 10% (Non-consecutive day)	Household	N = 1,255

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Ghosh-Jerath et al., 2021)	To determine link between production and access to food, DD and nutrient intake	Cross-sectional survey	India	Households with Non-pregnant (Chachra et al.) woman (15-49 years) and child (6-54 months)	-24-h dietary recall Multiple pass -FFQ	Quantitative	Non-consecutive 2 days	Household	N = 201
(Diana et al., 2019)	To analyze DD and DQ amongst women	Cross-sectional survey	Indonesia	Anemic pregnant women	-24-h dietary recall	Quantitative	2 days	Household	N = 152
(Gitagia et al., 2019)	To record Agrobiodiversity, DD and factors influencing them	Cross-sectional survey	Kenya	Women (18-49 years)	-24-h dietary recall -Semi quantitative questionnaire	Semi-quantitative	1 day	Household	N = 384
(Lamanna et al., 2019)	To check degree of agreement between Computer Assisted Telephone Interviewing (CATI) and Traditional methods	Validation study	Kenya	Households with woman (15-49 years) and child (6-23 months)	-24-h dietary recall -CATI	-	2 days	Household	N = 1,821
(Jomaa et al., 2020)	To investigate the links between household food insecurity (HFI) and mothers' sociodemographic, anthropometric, and dietary intakes	Secondary analysis of cross-sectional survey	Lebanon	Households with mother and their child (4-18 years)	-24-h dietary recall	Quantitative	1 day	Household	N = 1,204
(Hirvonen et al., 2016)	To assess role of seasonality on sources, intake of energy (per capita), and HDDS	Cross sectional survey	Ethiopia	Households	-4-d dietary recall	Quantitative	Twice a week in every month for 1 year	Household	N = 27,835
(Ngema et al., 2018)	To assess the determinants of food security status of households	Cross sectional survey	South Africa	Households	-24-h dietary recall	Qualitative and Quantitative	1 day	Household	N = 495

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Adubra et al., 2019)	To investigate agreement of MDD-W with household food insecurity and farm production diversity	Baseline survey of a 3-year intervention (Cross-sectional survey)	Mali	Households with mother-child pair	-24-h dietary recall -Android tablet	Qualitative	1 day	Household	N = 5,046
(Dulal et al., 2017)	To check association between Enhanced Homestead Food Production (EHFP) and DD of mother and child	Evaluation of ongoing intervention in 3rd year (Repeated cross-sectional survey)	Nepal	Mothers and children (6-23 months)	-7-day dietary recall	-	2 days	Household	N = 3,095 (2,101 mothers; 994 children)
(Shrestha et al., 2021)	To assess DD and associated factors in hilly regions with urban municipality	Cross-sectional survey	Nepal	Pregnant women	-24-h dietary recall	Semi-quantitative	1 day	Household	N = 327
(Samuel et al., 2019)	Comparison of DD in Cassava value chain households and non-Cassava value chain households	Descriptive cross-sectional survey	Nigeria	Households	-24-h dietary recall -FFQ	-	Non-consecutive 2 days	Household	N = 572 (391 women, 181 men)
(Brazier et al., 2020; Nsereko et al., 2020)	To assess DD and nutritional status of women in marginalized community	Repeated cross-sectional survey	Pakistan	Households with NPNL women (16-49 years)	-24-h dietary recall -Multiple pass method	Semi-quantitative	5 days	Household	N = 47
(Nsereko et al., 2020)	To discover modifiable risk factors for targeted interventions that aim to reduce Preterm birth	Prospective, longitudinal study	Rwanda	Pregnant women (18-49 years)	-24-h dietary recall -FFQ	-	1 day	University	N = 367

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Chakona & Shackleton, 2017)	To assess DD and establish relation between MDD-W and Household characteristics	Cross-sectional survey	South Africa	Women (15-49 years)	-48-h dietary recall -FFQ	-	4 days	Household	N = 554
(Gómez et al., 2020)	To establish relation between MDD-W and micronutrient adequacy amongst women from Latin American countries	Secondary analysis of cross-sectional survey	Brazil Colombia Costa Rica Chile Ecuador Peru Venezuela	NPNL women (15-49 years)	-24-h dietary recall -Multiple pass method	Quantitative	Non-consecutive 2 days	Household	N = 3,704
(Weerasekara et al., 2020)	To evaluate DD, nutrient adequacy, dietary and traditional food patterns in marginalized areas	Cross-sectional survey	Sri Lanka	Women (18-49 years)	-24-h dietary recall -Multiple pass method	Quantitative	1 day	Household	N = 400
(Madzorera et al., 2020)	To establish link amongst maternal DD, DQ with birth outcomes in pregnant women	Secondary analysis of placebo-controlled study	Tanzania	Pregnant women (18-49 years)	-24-h dietary recall	Quantitative	Once in a month, for 6 months	Health care facilities	N = 7,553
(Conti et al., 2021)	To inspect factors contributing to micronutrient adequacy in women	Cross-sectional survey	Tanzania	Women (14-49 years)	-24-h dietary recall	Quantitative	1 day	Household	N = 141
(Huang et al., 2018)	To recognize factors of maternal DD and its association with child growth outcomes	Longitudinal survey	Tanzania	Mother-child (under 24 months) pairs	-30-d dietary recall -FFQ	Qualitative	1 day	Health care facilities	N = 361
(Madzorera et al., 2021)	To examine role of prenatal maternal DD in infant growth	Secondary analysis of a birth cohort study	Uganda	Pregnant women (15-49 years)	-24-h dietary recall	-	1 day	Household	N = 3,291

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Arimond et al., 2010)	To create simple indicator that can be served as proxy to measure the micronutrient of women's diets	Secondary analysis of 24-h recalls (collected for distinct purposes)	Bangladesh Burkina Faso Mali Mozambique Philippines	Women (15-49 years)	-24-h dietary recall	Quantitative	Non-consecutive 2 days	Household	N = 2,560
(Yves Martin-Prevel et al., 2017)	To develop dichotomous indicator for assessing DD in women of reproductive age	Secondary analysis of 24-h recalls (collected for distinct purposes)	Bangladesh Burkina Faso Mali Mozambique Philippines Uganda	Women (15-49 years)	-24-h dietary recall -Multiple pass method	Quantitative	Non-consecutive 2 days	Household	N = 4,166
(Ahern et al., 2021)	To investigate seasonal variations in MDD-W and food group intake in regions where seasonal agricultural production and food availability have significant impact on DD	Repeated cross-sectional survey	Malawi Zambia	Women (15-49 years)	-24-h dietary recall	Qualitative	Once every month, for 11 rounds	Household	N = 200
(B. M. Kornatowski & S. S. Comstock, 2018)	To DD in women during their third trimester of pregnancy and establish relation with pre-pregnancy Body Mass Index	Secondary analysis of pregnancy cohort study	USA	Women (18+ years)	-24-h dietary recall -Self-administered questionnaires	Qualitative	1 day	Health care facilities	N = 40
(Gicevic et al., 2018)	To assess bonding of DD and DQ scores with gestational diabetes mellitus and hypertensive disorders of pregnancy	Prospective study	USA	Women (24-44 years)	-1-y dietary recall FFQ -Self-administered questionnaires	Semi-quantitative	Once every year, for 4 years	Health care facilities	N = 41,101

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Paré et al., 2019)	To determine the prevalence of wasting in children aged 6-23 months	Secondary analysis of Cross-sectional survey	Burkina Faso	Households with children 6-23 months of age	-24-h dietary recall	Qualitative	1 day	Household	N = 956
(Hipgrave et al., 2014)	To assess IYCF and anemia in central and western China	Cross-sectional survey	China	Households with children 6-23 months of age	-24-h dietary recall -FFQ	Semi-quantitative	1 day	Household	N = 2,244
(Wuneh et al., 2019)	To assess MMF and MDD	Cross-sectional survey	Ethiopia	Households with children 6-23 months of age	-24-h dietary recall -Open recall-based questionnaire	Qualitative	1 day	Household	N = 807
(Guja et al., 2021)	To examine concordance between mother and child diet diversity for designing intervention programs	Cross-sectional survey	Ethiopia	Mother and child pair (6-23 months age)	-24-h dietary recall -FFQ	Qualitative	1 day	Household	N = 796
(Kim et al., 2016)	To evaluate the effect of interventions on IYCF practices and anthropometry	Repeated cross-sectional survey	Ethiopia	Households with children 0-59 months of age	-24-h dietary recall	Qualitative	Twice, before harvest and after harvest at baseline and endline respectively	Household	N = 2,969
(Kamran et al., 2017)	To assess determinants of complementary feeding practices	Cross-sectional survey	Iran	Mothers of children aged 6-23 months	-24-h dietary recall -FFQ	Qualitative	1 day	Household	N = 576
(Chama, 2020)	To determine the contribution of edible non-timber forest products to nutritional status	Cross-sectional survey	Zambia	Households with mother and child (6-23 months) pair	-24-h dietary recall -List-based questionnaire -FFQ	Both Qualitative and Quantitative	1 day	Household	N = 158

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Modugu et al., 2022)	To determine influence of gender, migration, and HEEE factors on IYCF practices	Cross-sectional survey	India	Households with mother and child (6-23 months) pair	-24-h dietary recall -FFQ	Both qualitative and quantitative	1 day	Household	N = 325
(Wormer et al., 2021)	To determine the association between respiratory tract infections and IYCF practices	Cross-sectional survey	Suriname	Households with mother and child (12 months) pair	-24-h dietary recall	Qualitative	1 day	Household	N = 763
(Kogade et al., 2019)	To evaluate association of IYCF practices with sociocultural determinants	Cross-sectional survey	India	Mothers of children aged 0-23 months of age	-24-h dietary recall	-	1 day	Household	N = 612
(Solomon et al., 2017)	To assess the level of MDD and associated factors	Cross-sectional survey	Ethiopia	Mothers of children aged 6-23 months of age	-24-h dietary recall	Quantitative	1 day	Health care facility	N = 352
(Molla et al., 2021)	To determine dietary diversity and associated factors	Cross-sectional survey	Ethiopia	Households with mother and child (6-23 months) pair	-24-h dietary recall	Qualitative	1 day	Household	N = 665
(Dangura & Gebremedhin, 2017)	To determine diet diversity level and associated factors in Gorche district	Cross-sectional survey	Ethiopia	Households with mother and child (6-23 months) pair	-24-h dietary recall	Quantitative	1 day	Household	N = 417
(Mekonnen et al., 2017)	To determine MMF, MDD and associated factors	Cross-sectional survey	Ethiopia	Households with mother/caregiver and child (6-23 months) pair	-24-h dietary recall -FFQ	-	1 day	Household	N = 623
(Belew et al., 2017)	To determine MMF, MDD and associated factors	Cross-sectional survey	Ethiopia	Households with mother and child (6-23 months) pair	-24-h dietary recall -Open recall-based questionnaire	Qualitative	1 day	Household	N = 1,034

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Gezahegn & Tegegne, 2020)	To determine diet diversity and associated predictors in Gorche district	Cross-sectional survey	Ethiopia	Households with mother and child (6-23 months) pair	-24-h dietary recall -Open recall-based questionnaire	-	1 day	Household	N = 517
(Blackstone & Sanghvi, 2018)	To measure maternal, household, and MDD characteristics	Secondary analysis of cross-sectional survey	Bangladesh	Households with mother and child (6-23 months) pair	-24-h dietary recall	-	Twice in 4 years	Household	N_1 = 2,925 N_2 = 2,908
(Zhao et al., 2021)	To determine relation between dietary diversity, meal frequency, and early childhood developmental outcomes	Secondary analysis of cross-sectional survey	China	Households with mother and child (6-23 months) pair	-24-h dietary recall	Qualitative	1 day	Village clinic	N = 1,534
(Chilinda et al., 2021)	To explore the effect of household water access on MDD standards	Secondary analysis of cross-sectional survey	Malawi	Households with mother and child (6-23 months) pair	-24-h dietary recall	Qualitative	1 day	Household	N = 4,727
(Di Marcantonio et al., 2020)	To assess the dietary diversity and identify the associated factors	Cross-sectional survey	Somalia	Households with mother and child (6-23 months) pair	-24-h dietary recall	-	1 day	Household	N = 2,922
(Rubhara et al., 2020)	To assess the impact of cash crop production on household food security	Cross sectional survey	Zimbabwe	Households	-24-h dietary recall	Qualitative	1 day	Household	N = 281
(Gandure et al., 2010)	To analyze food security indicators used to assess households	Cross sectional survey	Zimbabwe	Households	-24-h dietary recall	Qualitative	1 day	Household	N = 178
(Cheteni et al., 2020)	To determine HDDS and food security	Cross sectional survey	South Africa	Households	-7-d dietary recall	Qualitative	1 day	Household	N = 296

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	Type	Collection frequency	Collection point	Sample size
(Kennedy, Berardo, et al., 2010)	To provide an overview and compare the performance of HDDS and FCS	Cross sectional survey	Burkina Faso Lao PDR Uganda	Households	-24-h dietary recall -7-d dietary recall -FFQ -List-based questionnaire	Qualitative	1 day	Household	N = 3,913
(McDonald et al., 2015)	To identify correlates of household food insecurity and poor dietary diversity	Baseline survey of an intervention	Cambodia	Households	-24-h dietary recall	Quantitative	1 day	Household	N = 900
(Schwei et al., 2017)	To define a relationship between HDDS, food security, and consumption of Vitamin A-rich foods	Cross sectional survey	Ethiopia	Households	-24-h dietary recall -List-based questionnaire	Qualitative	1 day	Household	N = 300
(Aweke et al., 2021)	To examine the impact of agricultural technologies on household food and nutrition security	Cross sectional survey	Ethiopia	Households	-24-h dietary recall -7-d dietary recall -FFQ	Quantitative	1 day	Household	N = 248
(Melaku et al., 2018)	To use dietary patterns as alternative to diet diversity scores, and investigate their association with childhood stunting	Cross sectional survey	Ethiopia	Households with mother child pair	-24-h dietary recall	Qualitative	1 day	Household	N = 3,788
(O'Meara et al., 2019)	To examine diet diversity in indigenous food-producing households	Cross sectional survey	Fiji	Households	-24-h dietary recall -Open recall-based questionnaire	Qualitative	1 day	Household	N = 161

Author / Year	Research aim	Study design	Country	Target audience	Dietary Data				
					Methodology	**Type**	**Collection frequency**	**Collection point**	**Sample size**
(Mahmudiono et al., 2017)	To explore the relationship between child stunting and household dietary diversity	Cross sectional survey	Indonesia	Households with children below 5 years of age	-24-h dietary recall	Qualitative	1 day	Household	N = 736
(Jones et al., 2014)	To explore relationship and identify determinants between production diversity of household farms and HDDS	Secondary analysis of Cross-sectional survey	Malawi	Households	-24-h dietary recall -7-d dietary recall -FFQ	Quantitative	1 day	Household	N = 6,623
(Nkonde et al., 2021)	To determine effect of agricultural diversification on household dietary diversity	Secondary analysis of Longitudinal survey	Zambia	Households with children below 5 years of age	-24-h dietary recall	Qualitative	1 day	Household	N = 7,934
(Khumalo & Sibanda, 2019)	To determine the contribution of agriculture in food security status of households	Cross sectional survey	South Africa	Households	-24-h dietary recall -Open based and list-based questionnaire -4-w dietary recall	Quantitative	1 day	Household	N = 208
(Cordero-Ahiman et al., 2021)	To analyze different factors determining HDDS	Cross sectional survey	Ecuador	Households	-7-d dietary recall	Qualitative	1 day	Household	N = 383
(Roba et al., 2019)	To assess different indicators of household and individual food security status	Longitudinal survey	Ethiopia	Households	-24-h dietary recall -7-d dietary recall -1-m dietary recall -FFQ	Qualitative	Twice (before and after harvest season)	Household	N = 800

2.3 Results

2.3.1 Description of the studies

The context and methodology used in the 80 research studies included in this review are summarized in Table 1. The studies have evidence from 38 countries, including one from Oceania (Fiji), two from North America (United States and Costa Rica), seven from South America (Brazil, Chile, Colombia, Ecuador, Peru, Suriname, and Venezuela), twelve from Asia (Bangladesh, Cambodia, China, India, Indonesia, Iran, Laos, Lebanon, Nepal, Pakistan, Philippines, and Sri Lanka) and sixteen from Sub-Saharan Africa (Benin, Burkina Faso, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Somalia, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe). Seven studies present findings from multiple countries (Ahern et al., 2021; Arimond et al., 2010; Gómez et al., 2020; Hanley-Cook et al., 2020; Kennedy, Berardo, et al., 2010; Y Martin-Prevel et al., 2017; Nguyen et al., 2020). In terms of their purpose, there was significant heterogeneity across 80 studies regarding association with micronutrient adequacy, household food insecurity, agricultural food production diversity, seasonal food patterns, food purchasing practices, women empowerment, antenatal care practices, maternal health care, child growth, child stunting, prevalence of anemia, and bone fractures. Two studies were designed in response to an increased demand for an indicator that can be expressed in terms of the prevalence of meeting a minimum acceptable level of diet diversity in women of reproductive age, resulting in the development of MDD-W as a dichotomous indicator (Arimond et al., 2010; Y Martin-Prevel et al., 2017). Most of the studies were cross-sectional surveys that looked at association rather than causation. With sample sizes ranging from 40 in a pregnancy cohort study (B. M. Kornatowski & S. S. J. P. Comstock, 2018) to 41,101 in a prospective study (Gicevic et al., 2018), the number of households or individuals surveyed in these studies varied substantially.

2.3.2 Critical appraisal of dietary data collection methodology

For data collection, seventy-eight of the eighty studies employed well-trained interviewers to deliver face-to-face interviews to respondents, while two studies employed self-administered recalls. Three studies reported data collection through tablet-based surveys (Hanley-Cook et al., 2020; Jones et al., 2018; Lamanna et al., 2019). Only one study, amongst the eighty, used computer-assisted telephone interviewing in addition to interviewer-assisted face-to-face recall (Lamanna et al., 2019). All food items in dietary recalls were classified into major food groups as defined in the MDD-W, IYCF-MDD, and HDDS guidelines. Traditional and mixed foods, such as chicken curry and pizza, were disintegrated into respective ingredients and then included in their relevant food groups. The diet diversity score was then calculated by adding the total number of food groups consumed by an individual or the household in a 24-h period. Interviewers were required to attend training sessions on the study objective, data collection procedure, sampling method, ethical issues, data entry, and data management before travelling into the field in almost all the seventy-eight studies. In two studies, employing self-administered recalls (Gicevic et al., 2018; B. M. Kornatowski & S. S. J. P. Comstock, 2018), trained professionals were required at later stages to assess dietary data from forms. It should be highlighted that, unlike most studies, neither of these two kinds of research were undertaken in resource-poor settings. In the context of recalls, sixty-seven studies employed 24-h recalls, three studies employed 7-d recall, five studies employed both 24-h and 7-d recall, and the remaining five studies employed 48-h recall, 4-d recall, 30-d recall, 1-y recall, and both 24-h and 4-w recall, respectively. The recalls were administered using list-based, open recall-based, or food frequency questionnaires. Although quantitative recalls can be challenging, especially in settings with low literacy rate, recalls practiced in twenty-eight studies were quantitative, thirty-three were qualitative, five were semi-quantitative, three were both quantitative and qualitative, and eleven studies did not report on the type of recall. Dietary data was collected once in fifty-two studies, twice in fifteen studies, and more than twice in the remaining studies. Data was collected from respondent's household in sixty-eight studies, health care facilities in ten studies, and universities in two studies.

Amongst different methodologies, although there is no fixed gold standard diet evaluation method, the quantitative 24-h recall has been frequently employed in variety of applications such as describing intakes, examining associations, and evaluating the effects of interventions. Nevertheless, we cannot rule out the possibility of recall bias since retrospective methods tend to underestimate or overestimate actual food consumption for various reasons, including forgetfulness (Dwyer et al., 1989). Workshops for interviewers, including classroom training and fieldwork are required for the collection of high-quality data with minimal bias (Hanley-Cook et al., 2020). Three studies reviewed in this paper evaluate the validity of different methodologies used for data collection (Hanley-Cook et al., 2020; Lamanna et al., 2019; Nguyen et al., 2020). Hanley-Cook et al. (2020) assessed the relative validation of qualitative list-based and open recall-based methods with reference to weighed food records. It was discovered that in these three countries (Cambodia, Ethiopia, and Zambia), both list-based and open recall-based methods were prone to misreport consumption of certain food groups. Reporting of food items that were not consumed in sufficient quantity, i.e. less than 15 grams for MDD-W, resulted in overreporting for both methods by 10%. These results were consistent with the findings of the second validation study conducted in India and Bangladesh (Nguyen et al., 2020), in which they assessed validation of qualitative list-based with reference to quantitative open recall-based methodology. The third validation study evaluated the performance of computer-assisted telephone interviewing (CATI) for collecting dietary data from African women in large-scale studies (Lamanna et al., 2019). The findings of this study revealed that switching from traditional in-person interviews increased the diet diversity scores by 11-14% in some indicators. This discrepancy could be the consequence of sensitive probes, which may unveil unfavourable information about the responder. The responses demonstrated a significant social-desirability bias, which can be mitigated by changing the mode of data collection.

2.4 Discussion

The review has attempted to describe all methodological aspects applied in diet diversity indicator studies, to critically assess the limitations of traditional methodology. According to findings of the review, most studies have employed interviewer-administered 24-h recalls to assess dietary diversity. However, every method possesses constraints that affect data collection and thus undermine conclusions of the research, especially if reported errors are not addressed to the maximum extent possible, using appropriate tool selection. Since they rely on memory and social perception of questions asked, major drawbacks include recall (Bukari, 2021) and social-desirability bias (Lamanna, 2019). Furthermore, traditional methodology necessitates a significant amount of effort on part of the interviewer to probe and transcribe the respondent’s dietary intake, which comes with a high chance of errors and time-related costs (Thompson, 2010). Technology adaptation has resulted in notable changes in dietary assessment methodologies, all of which have a favourable effect on cost, respondent-researcher workload, efficiency of data collection, coding and processing of dietary intakes, response rates, and the consistency of assessment measures (Long, 2013). Since personal digital assistants (PDAs), tape recorders, scan- and sensor-based technologies have all become outdated, and all operations of web-based or computer-based platforms/ software can now be performed on smartphones, dietary evaluation via a smartphone-based application has a great potential (Bucher Della Torre, 2017). According to prior studies, smartphones are convenient, easy to use, and handy, thus preferred over conventional methodologies for recording dietary data (Carter, 2013). Additionally, smartphones possess the ability to overcome the shortcomings of conventional methodologies (Hongu, 2011; Illner, 2012).

2.4.1 Respondent bias

2.4.1.1 Recall

Dietary recalls ask respondents to remember and report all foods and beverages consumed in a specific time period, usually the preceding day's 24 hours. Dietary recalls are conducted without prior notice, eliminating the risk of reactivity (Thompson, 2010). The use of a local interviewer to administer recall minimizes the literacy barrier and aids recall. However, many respondents have trouble distinguishing between what they consume habitually and what they ate the day before, leaving the door open to omissions and intrusions (Guinn, 2008). The human ability to recall events fades over time, beginning within an hour after the meal consumption (Baxter, 1997). It can be deduced that longer the recall period, greater is the bias (Dulal, 2017). Furthermore, recalling foods eaten away from home is equally dependent on memory, which may reduce the validity of dietary recalls (Zhang, 2020). Recall accuracy can be enhanced if executed several times over 24 hours, hence minimizing the intrusion rate by shifting to a record-like approach from the recall approach (Lu, 2006). This can be accomplished by using a smartphone application that, due to its portability, can be carried around by respondents at all times and collects real-time self-administered dietary data on foods consumed via digital recording rather than through paper questionnaires. This will reduce the amount of effort and time required to fill out and decipher conventional forms in 24-h recall interviews, while increasing respondent motivation to record meals (Bucher Della Torre, 2017).

2.4.1.2 Social-desirability

Social-desirability bias is the tendency of respondents to answer questions in a way they hope will be considered favorable by others (Krumpal, 2013). Generally, when the survey process is more socialized, respondents are more likely to give answers that are considered desirable by society (Lamanna, 2019). In dietary surveys, the bias can appear as over-reporting of "healthy diets" and under-reporting of "unhealthy diets". Additionally, biases based on the gender of the interviewer are becoming more prevalent in the developing world. In one of the MDD-W studies, evidence was found that male interviewers were more likely to record lower diet diversity scores than female interviewers (Lamanna, 2019). At the point, when respondents are unsure about the interviewer's probable response, or when the noting cycle does not include any relationship with others, the responses are based more on what respondents actually know or consume (Cerri, 2019). The main cause of social-desirability bias, such as the presence of an acquaintance or interactions with the interviewer (Getacher, 2020), can be avoided by switching from current traditional practices to technology-based methodologies. By ensuring respondent's privacy, a smartphone app that allows them to record their dietary data without engaging in face-to-face interactions, by logging into their personal account, could help reduce social-desirability and gender-bias. Such biases in data recording are well documented, but the link between them and data collection methodology needs to be investigated further.

2.4.2 Interviewer training and burden

In-person interviews using traditional list-based or open recall-based questionnaires have their own set of functional benefits and drawbacks. The list-based methodology demands less interviewer capacity and training time; nonetheless, its implementation can be more time-consuming and prone to food misclassification, particularly for foods taken in little amounts (Nguyen, 2020; Martin-Prevel, 2010). For example, in a study conducted in India, milk added to tea, and onions or tomatoes added in mixed dishes were not identified by the list-based method (Nguyen, 2020). On the other hand, an open recall-based methodology can provide a more accurate and comprehensive recall of all food items consumed; however, it requires additional training and more skilled enumerators who have a working knowledge of local foods and recipes. (Gibson, 2017). In most of the studies, workshops on training and confidence-building were required during the preparatory phase to ensure precise and effective data collection. Following the collection of dietary information, incomplete columns were cross-checked, and paper questionnaires were meticulously numbered to preserve the record and privacy of respondents (Getacher, 2020). Moreover, to ensure consistency, educated local personnel were required to develop questionnaires first in English, followed by a translation in local language, and finally back to English (Getacher, 2020; Girma, 2019; Dulal, 2017. In one study (Hanley-Cook, 2020), the interviewers accompanied the respondents to measure the portion of foods consumed away from the household. To enhance interviewer confidence and assess the validity of data collection, some studies conducted small pilot surveys prior to the actual surveys. All these factors together add up to a significant increase in interviewer effort and time to collect the data. An interviewer-administered 24-h dietary recall via the 'Automated Multiple-Pass Method' (AMPM) can take 45-60 minutes in completion (Galea, 2017), increasing both respondent and interviewer burden. On the other hand, smartphone applications that ask structured questions about date/time, occasion of consumption, food name, constituent ingredients, portion size or number of servings, and where the meal was prepared or consumed, would not only reduce the interviewer's workload, but also allow respondents to track their meals in their own time. Dietary planning is predominantly the duty of women in resource-poor settings. As a result, male interviewers can be less knowledgeable about the constituents of mixed dishes (Lamanna, 2019). A robust database containing the nutritional content of cooked and uncooked local foods linked with the application might reduce the labor involved in data collection, coding, analysis and provide the results at same time. This will result in a decrease in the dietary data's reliance on the interviewer's skill and ability. Prior studies have found a high level of agreement between traditional and modern approaches, with the latter being preferred by a majority of participants.

2.4.3 Cost-time constraints

In the field of dietary assessment, there is increasing pressure to enhance the accuracy, while lowering the data collection and processing cost involved in traditional methodologies (Eldridge, 2019). Training and data collection, which involves interviewing, coding, processing, and quality control, demands a significant amount of cost, and time during the research process. Dietary assessment studies commonly adopt technology to reduce the cost and complexity involved in collecting and processing dietary intake data (Thompson, 2010). A study comparing different sampling methods among wine consumers claimed that the cost of a face-to-face survey was 2-2.5 times higher than the online surveys (Szolnoki, 2013). In Kenya, while comparing the strengths and limitations of CATI with reference to face-to-face interviews, it was revealed that the former was determined to cost 5 US$ per survey and the latter was determined to cost 16 US$ per survey (Lamanna, 2019). Recently, a large number of 24-h recalls, and FFQ are being administered via modern technologies pertaining to lower costs (Thompson, 2010). Furthermore, the primary disadvantage in the majority of the diet diversity indicator studies assessed was single-day data collection and limited sample sizes, which can be suppressed by smartphone applications, since no significant supplementary cost is required to expand the number of entries or participants. Researchers leading the development of ‘Automated Self-Administered 24-h Recall’ (ASA24) pointed out that research opportunities may arise from significant cost savings provided by newer technologies when compared to the equivalent quality of data (Kirkpatrick, 2014).

Although most of the studies reviewed in this paper have not mentioned about how long the interviews took, studies conducted in Ethiopia (Getacher, 2020) and Lebanon (Jomaa, 2020) revealed that interviews lasted an average of 30-minutes and 45-minutes, respectively. Longer interviews can be a demotivating element for respondents taking part in nutritional surveys. Respondents who are preoccupied with their work, may systematically disregard traditional time-consuming surveys and prefer smartphones over them. Smartphone applications can help in speeding up the data collection and analysis process. ‘My Meal Mate’, (Carter, 2013) a weight-loss smartphone app, took an average of 7 minutes to record a meal, compared to 8.5 minutes for ‘DietMatePro’ (Beasley, 2008) and 5 minutes for the ‘Wellnavi’ PDA device (Wang, 2006). Respondents reported spending an average of 22 minutes per day using the ‘My Meal Mate’ smartphone application for recording meals, which is comparable to a 24-h recall. However, the amount of time spent manually coding the data collected in the traditional method is far longer than with the smartphone application, which does not require any additional coding effort.

Also, the present situation of a novel virus, COVID-19, which spreads by encountering droplets of infected fluid (Organization, 2020), respondents might not be interested in participating in dietary surveys involving face-to-face interactions. A recent review centered on the efficiency and quality of data collection of studies during the COVID-19 pandemic revealed that 92% of studies collected data through web-based or app-based surveys (Lin, 2021).

Despite increasing popularity and ownership, smartphones are still not universal and have some limitations. There were legitimate concerns that new technology acceptance would be low among various population segments (even with access), notably among those who were not technologically skilled or knowledgeable (Timmins, 2014). Prior research has demonstrated that respondents who were not using mobile devices, stated that they will not participate in a survey that does not allow them to maintain a paper diary, as an alternative to the technology-based approach (Timmins, 2014). Switching from traditional methods may necessitate respondent training on tool usability and might increase their workload in absence of the interviewer (Ortega, 2015). 'Response fatigue' is associated with self-administered respondent recordings, that last more than four consecutive days (Gersovitz, 1978). Therefore, as the week progresses, the accuracy of dietary data being recorded by the respondent might more likely be compromised. Moreover, it has been acknowledged that well-off, educated, and knowledgeable respondents tend to make a major proportion of technology-based surveys (Amoutzopoulos, 2018). Being more informative, they can have better dietary habits and diet diversity scores. Consequently, collecting data via smartphones can be biased if the population that can be reached via smartphone differs from the general population (non-coverage bias) or if the responding population differs from the non-responding population (non-response bias) (Lamanna, 2019).

However, the collection of data by mobile phones has evolved over time, from a rarely used and frequently criticized method to a dominant mode of data collection all over the world (Szolnoki, 2013). By reducing the duration involved in collecting and reporting food consumption data, while enhancing the quality by limiting misreporting errors, newer technologies have gained an edge over traditional methodology (Amoutzopoulos, 2018). Automated dietary assessment methods have the potential to reduce respondent and researcher burden while giving the flexibility of a prospective method in terms of food reporting (Carter, 2013). Even though the methodological features of smartphone applications and traditional methods might frequently overlap, smartphones have the potential to improve dietary assessment by allowing lesser respondent-researcher burden, more cost- and time-effective data collection, a wider geographic reach, and greater respondent acceptability.

2.5 Conclusion

The review has attempted to describe all methodological aspects implemented in MDD-W, IYCF-MDD, and HDDS studies to critically assess the limitations in traditional methodology and fill the gap with inventive smartphone application that works in tandem with technology and modernity. Traditional methods have inherent limitations, such as recall bias, social desirability bias, interviewer burden, and cost-time constraints, which impair data collection and thus undermine the research conclusions. Smartphone adaptation might result in notable changes in dietary assessment methodologies to make a favourable effect on cost, respondent-researcher workload, efficiency of data collection, coding and processing of dietary intakes, response rates, and the consistency of assessment measures. In conclusion, while the transition from conventional to smartphone applications is recommended for collecting dietary data, the relationship between the efficiency, effectiveness, and quality of data collection using both methodologies warrants further investigation.

FOREWORD TO CHAPTER III

This chapter reports the design, development, and features of 'Diet DQ Tracker', a self-administered smartphone application to collect dietary data for diet diversity indicators MDD-W, IYCF-MDD, and HDDS. The application was linked with a robust food database conforming to the methodology of diet diversity and diet quality indicators. A desktop-based CMS application was developed to store, manage, and visualize the dietary data collected from the application and update the food composition database at regular intervals.

CHAPTER III

DESIGN AND DEVELOPMENT OF 'DIET DQ TRACKER': A SMARTPHONE APPLICATION FOR AUGMENTING DIETARY ASSESSMENT

Abstract

Background: The usage of mobile phones for data collection in dietary surveys has evolved over time, from a rarely used and frequently criticized method to a dominant mode of data collection throughout the world.

Objective: 'Diet DQ Tracker' is developed with the goal of creating a self-administered mobile phone application that could potentially replace traditional methods of collecting dietary data, such as in-person or phone call interviews using a pen and paper questionnaire or tablets. The app's primary objectives are: (1) To collect dietary data that can be used to assist intervention programmes in resource-poor settings. (2) Facilitate self-monitoring of diet via real-time dietary feedback based on the diet diversity and diet quality indicators.

Method: 'Diet DQ Tracker' is designed for real-time meal recording from a list of pre-defined food items and provides personalized dietary feedback based on diet diversity indicators for women of reproductive age (MDD-W), infants and young children (IYCF-MDD), households (HDDS), and SAIN, LIM nutrient profiling system. All meal entries of a particular date are analyzed and visualized collectively in the app, followed by permanent cloud storage that can be retrieved via desktop-based CMS application.

Result and conclusion: 'Diet DQ Tracker' is the first smartphone application designed to collect data for globally recognized diet diversity indicators used in resource-poor settings. A comprehensive database of foods items from USDA, Laos, and Ethiopian food composition table (8777 foods and beverages) linked to the application reduces the effort, time, and resources required to collect data. In addition, the automated process of coding and score calculation empowered by database, generates the output results simultaneously and reduces the need for interviewer training and skill for dietary data collection.

Keywords: Diet diversity, dietary assessment, mobile phone app

3.1 Introduction

Global food security and nutrition continue to be at the forefront of the development agenda. Individual nutrition enhancement is being given much attention in meeting this global need. At the center of nutrition improvement, the United Nations agencies have been dedicating efforts towards improving the nutritional level of populations, especially in developing countries. However, methods to capture the contribution of food systems adequately and systematically in nutrition research, although laudable, are currently not as efficient as they might be since many of them involve data collection with the pen and paper approach. These methods are time-consuming, sometimes subject to error, and can be cumbersome in terms of data entry and analysis. Thus, the development of user-friendly methods such as smartphone technologies have a tremendous potential to capture detailed dietary information of individuals and groups much more efficiently.

Nutritionists have long recognized that high-quality diets are influenced by dietary diversity. Most dietary guidelines around the world, encourage increasing food diversity across and within food groups, as it is expected to provide an appropriate intake of vital nutrients and promotes good health. The lack of food diversity is particularly problematic among poor populations in developing nations. Their diets are primarily based on starchy staples and are often lacking in animal products, and fresh fruits and vegetables (Black et al., 2013). An adequate diet meets the individual's energy and essential nutrient requirements. Diet-related chronic diseases and obesity have shifted the definition of quality diet towards moderation, proportionality, and diversity. Diet diversity is one of the key features of diet quality (Ruel et al., 2013).

In public health research, identifying and quantifying the usual diet is critical for improving understanding of population food intakes, diet quality, dietary determinants, and diet-disease interactions. The difficulties of establishing reliable dietary assessments have been widely researched and debated (Subar et al., 2015). As a result, dietary assessment tools must be selected in consideration of the relative validity of different methodologies, respondent-researcher burden, and resources required for implementation (Willett, 2012). In nutritional research, traditional methods such as 24-h recalls, food records, food frequency questionnaires (FFQs), and interviews are the frequently practiced methodologies for determining food consumption intake (Thompson et al., 2015). These methods are hampered by limitations, which affect the data collection and weaken the conclusions, especially if the error in reporting is not addressed to the maximum extent possible by selecting the correct tools and utilizing appropriate statistical techniques (Boeing, 2013). Normally, an interviewer determines an individual's food intake by asking questions from a questionnaire and recording the information on a paper. Following this approach, the dietary diversity intake is calculated manually, by using food composition tables, or by using different software. This method entails numerous repeating steps that require a lot of human effort (Ferreira et al., 2015). Considering inherent difficulties such as dependency on memory, time consumption, food portion measurement, educated or experienced personnel, coding burden, food expertise, and other time-consuming chores (Willett, 2012), it has been suggested that utilizing mobile technologies may result in an improved assessment of food consumption and personalized nutritional feedback (Cade, 2017). The use of mobile phones to assess food consumption intake or enhance the assessment of food consumption intake has been explored in several studies (Ambrosini et al., 2018; Ashman et al., 2017; Boushey et al., 2017; Bucher Della Torre et al., 2017; Carter et al., 2013; Chae et al., 2011; Higgins et al., 2009; Kong & Tan, 2012; Pendergast et al., 2017). A review of 74 studies that used innovative technologies to improve diets found that, while traditional methods and new technologies often overlap in methodology, new technologies may deliver more accurate nutritional assessment by allowing cost- and time-efficient data collection and increased respondent acceptability (Illner et al., 2012). As reported in a pilot survey in Australia, 96% of female respondents aged 15-40 kept their smartphones with them throughout the day, making mobile apps readily accessible regardless of the location (Redmayne, 2017).

Many mobile apps have been developed for distinct goals and validated against 24-h dietary recall, such as 'Eat and Track' (EaT) (Wellard-Cole et al., 2019), 'My Meal Mate' (MMM) (Carter et al., 2013), 'electronic Dietary Intake Assessment' (e-DIA) (Rangan et al., 2015), 'Easy Diet Diary' (Ambrosini et al., 2018) and 'electronic Carnet Alimentaire' (e-CA) (Bucher Della Torre et al., 2017). As far as we know, none of the mobile apps available, collects self-reported data on diet diversity indicators, that have been developed for use at the population levels in resource-poor settings. These diet diversity indicators include Minimum Dietary Diversity for Women (MDD-W) and Minimum Dietary Diversity of Infant and Young Child Feeding practices (IYCF-MDD) at the individual level, and Household Dietary Diversity Score (HDDS) at the household level. We have developed ‘Diet DQ Tracker’: a self-administered smartphone app designed for iOS and android to facilitate data collection for diet diversity indicators. ‘Diet DQ Tracker’ includes a customized database of 8777 food items from USDA, Ethiopia, and Laos, which are grouped into relevant food groups using the diet diversity indicators methodology. In addition, a desktop-run CMS software ‘NutriMetrics_CMS’ has been developed to facilitate database management and analysis of the results. This study aims to detail the design, development, and functionalities of the new self-administered smartphone app ‘Diet DQ Tracker’.

3.2 Materials and methods

3.2.1 Diet diversity indicators

The frequently used method to measure diet diversity for individuals or households consists of evaluating the variety or number of different food groups (rather than food items) consumed in a specific period. Higher is the score; higher will be the diversity in diet (Ruel et al., 2013). Depending on the level of measurement and intended purpose, the number of food groups may vary in different indicators (Torheim et al., 2010). At the individual level, these indicators reflect micronutrient adequacy whereas for households, diet diversity is an indicator of access to food, such as the household’s capacity to acquire food. In both theoretical and practical contexts, diet diversity indicators have been developed and used in many ways. Nevertheless, only a few simple indicators have been nurtured for population level use in resource-poor settings. These globally accepted indicators include Minimum Dietary Diversity for Women (MDD-W), Minimum Dietary Diversity of Infant and young child feeding practices (IYCF-MDD), and Household Dietary Diversity Score (HDDS) (Verger et al., 2019). The food groups used to calculate these indicators scores are mutually exclusive, which means that no food or ingredient can be classified in more than one food group. All food groups are equally weighted when calculating the score, and each food group is counted only once every 24 hours, regardless of the number of food items consumed from that group.

3.2.1.1 Minimum dietary diversity for women (MDD-W)

MDD-W is a dichotomous indicator of whether women 15–49 years of age have consumed at least five out of ten defined food groups the previous day or night. The percentage of women between the ages of 15 and 49 who meet this minimum can be used as a proxy indicator for better micronutrient adequacy, which is one of the most important aspects of diet quality (FAO, 2016). The following ten food groups count for the score: 1. Grains, white roots and tubers, and plantains; 2. Pulses (beans, peas and lentils); 3. Nuts and seeds; 4. Dairy; 5. Meat, poultry and fish; 6. Eggs; 7. Dark green leafy vegetables; 8. Other vitamin A-rich fruits and vegetables; 9. Other vegetables; 10. Other fruits. The MDD-W score is a numeric value between 0 and 10, based on the consumption of food items weighing equal to or more than 15 grams from each of these food groups (FAO, 2016). Along with these ten food groups, MDD-W includes six optional and two required categories that are not factored into the score calculation. The optional categories are: 1. Insects and other small protein foods; 2. Red palm oil; 3. Other oils and fats; 4. Savoury and fried snacks; 5. Sweets; 6. Sugar-sweetened beverages. The required categories include: 1. Condiments and seasonings; 2. Other beverages and foods (FAO, 2016).

3.2.1.2 Infant and young child feeding practices – minimum dietary diversity (IYCF-MDD)

Nutritional status and child survival rate of children below two years of age are directly related to Infant and young child feeding (IYCF) practices. Therefore, it is vital to improve IYCF practices in children aged 0–23 months in order to promote nutrition, health, and development of children. Minimum dietary diversity (MDD) is one of the eight core indicators of IYCF practices (Organization, 2008). MDD is defined as whether children between the age group of 6-23 months have consumed food from five or more food groups, out of eight food groups in the last 24 hours. The eight food groups that count for calculating IYCF-MDD score are: 1. Breast milk; 2. Grains, roots, and tubers; 3. Legumes and nuts; 4. Dairy products (milk, yogurt, cheese); 5. Flesh foods (meat, fish, poultry, and liver/organ meats); 6. Eggs; 7. Vitamin-A rich fruits and vegetables; 8. Other fruits and vegetables. The IYCF-MDD score is a numeric value between 0 and 8 based on the consumption of any quantity of food items amongst each of these food groups within a 24-h period (Organization, 2008).

3.2.1.3 Household dietary diversity score (HDDS)

HDDS calculates the number of different food groups (out of 12 food groups) consumed over a 24-h period and is an attractive proxy indicator for household's food diversity. HDDS is focused on the desired outcome of improved food access i.e., improved household food consumption (Swindale & Bilinsky, 2006). The twelve food groups that are used for calculating HDDS are: 1. Cereals; 2. Root and tuber; 3. Vegetables; 4. Fruits; 5. Meat, poultry, offal; 6. Eggs; 7. Fish and seafood; 8. Pulses/legumes/nuts; 9. Milk and milk products; 10. Oil/fats; 11. Sugar/honey; 12. Miscellaneous. The HDDS score is a numeric value between 0 and 12 based on the consumption of food prepared at home consumed by any member of the household, irrespective of food quantity, from twelve food groups within a 24-h period. The HDDS measure provides an overview of a household's food access across a 24-hour period (Swindale & Bilinsky, 2006). In contrast to MDD-W and IYCF-MDD, HDDS does not have a cut-off value for indicating adequate diet diversity of the household.

3.2.2 Diet quality indicator

The term diet quality has emerged in the scientific literature over the last two decades, most frequently in nutritional epidemiology for assessing the efficacy of dietary interventions and dietary habits at the population level (Drewnowski et al., 1996; Patterson et al., 1994). Diet quality has been introduced as a risk assessment tool for cancer, mortality, and cardiovascular disease risk prediction by researchers (Key, 2007). Until now, most of the dietary guidelines for health promotion have been largely based on data from single foods and nutrients, but foods are not consumed in isolation. There has been an increased amount of attention to assess the quality of whole diet, by taking the diet's complexity along with possible synergistic and antagonistic influences among its various components into consideration (Jacobs Jr & Steffen, 2003). Diet quality measurement methods have evolved in recent years, with the emergence of a variety of indices and scoring systems. In more refined diet quality scoring methods, protective dietary patterns and unfavorable food intakes are identified (Wirt & Collins, 2009). As a relatively new concept, it measures both the quality and variety of an individual's diet, allowing the exploration of the relationship between the whole food and state of health (Wirt & Collins, 2009).

SAIN, LIM is a nutrient profiling system that categorizes food items into four classes by evaluating two independent scores, SAIN i.e., score of nutritional adequacy of individual foods (positive or qualifying nutrients), and LIM i.e., score of nutrients to be limited (negative or disqualifying nutrients) (Darmon et al., 2005; Maillot et al., 2007). The SAIN score's limited number of nutrients (five primary nutrients and one optional nutrient) are determined by striking a balance between nutrients of public health importance, nutrient markers of essential food categories, and the requirement for a feasible nutrient profile in the research settings (Masset et al., 2015). Protein, fibre, ascorbic acid, calcium, and iron are the primary nutrients, while vitamin D is an optional nutrient used in calculating SAIN score. The SAIN score is unweighted arithmetic mean of the percentage adequacy of five positive nutrients and one optional nutrient (Vit. D), calculated for 100 kcal of food as following, where $nutrient_{ip}$ is the quantity (g, mg, or μg) of positive nutrient p in 100 g of food i, RV_p is the daily recommended value for nutrient p, and E_i is the energy content of 100 g of food i (in Kcal/100 g) (Darmon et al., 2009).

$$SAIN_i = \frac{\sum_{p=1}^{p=5} ratio_{ip}}{5} \times 100 \qquad 1$$

with

$$ratio_{ip} = \left[\frac{nutrient_{ip}}{RV_p}\right] \times \frac{100}{E_i} \qquad 2$$

The LIM score is the mean percentage of the maximal recommended values of three negative nutrients i.e., sodium, added sugars, and saturated fatty acids. The LIM score for 100 g of food is calculated as following, where $nutrient_{il}$ is the content (g, mg) of limited nutrient l in 100 g of food i, and MRV_l is daily maximal recommended value for nutrient l (Darmon et al., 2009).

$$LIM_i = \frac{\sum_{l=1}^{l=3} ratio_{il}}{3} \qquad 3$$

with

$$ratio_{il} = \left[\frac{nutrient_{il}}{MRV_l}\right] \times 100 \qquad 4$$

By calculating SAIN, LIM score, the food items are categorised under four classes: Recommended foods (class 1) if SAIN score is >= 5 and LIM score is < 7.5, Neutral foods (class 2) if SAIN score is < 5 and LIM score is < 7.5 , Eat less of these foods (class 3) if SAIN score is >= 5 and LIM score is >= 7.5, and Limit these foods (class 4) if SAIN score is < 5 and LIM score is >= 7.5 (Darmon et al., 2009).

3.2.3 Design and architecture

'Diet DQ Tracker' has been designed as a self-administered smartphone app that could potentially replace traditional method of dietary data collection, such as in-person interview via pen and paper questionnaire. 'Diet DQ Tracker' aids in overcoming the limitations of traditional methods by utilising iOS or Android-based mobile devices. The app's primary objectives are: (1) To collect dietary data that can be used to assist intervention programmes in resource-poor settings. (2) To facilitate self-monitoring of diet via real-time dietary feedback based on the diet diversity indicators (MDD-W, IYCF-MDD, and HDDS), and the nutrient profiling system (SAIN, LIM). An extensive food and beverage database was developed, integrated, and stored in the third-party cloud services, linked with the app. In the database, the ingredients of food items are classified according to different food group categories of dietary indicators. The nutritional composition of food items contains the amount of energy, protein, fibre, calcium, iron, vitamin c, vitamin d, added sugar, saturated fatty acids, and sodium, aiding in calculating the SAIN, LIM score. The app provides real-time dietary feedback even in the absence of cellular data or wi-fi, by permanently storing food database imported from third-party cloud services into the app. After the user enters food items into the search as you type text box, the database enables the app to perform calculations in the backend and generate the output score. If the app is connected to the internet, dietary data logged in the app is transferred to the cloud; however, in the absence of internet, both input and output data are stored in the app, allowing the app to perform its core functions even in remote areas with limited or no internet access. The data from user's 'Diet DQ Tracker' account is transferred from cloud to the desktop-based local Content Management System (CMS) app, which is managed by an administrator. The dietary data present in research administrator's CMS app can be exported as a comma-separated values file (CSV) for detailed analysis. The structure of the 'Diet DQ Tracker' algorithm is illustrated in Figure 3.2. The algorithm was coded in the python language, and it is available at the 'Food Engineering Lab' of McGill University, Macdonald Campus.

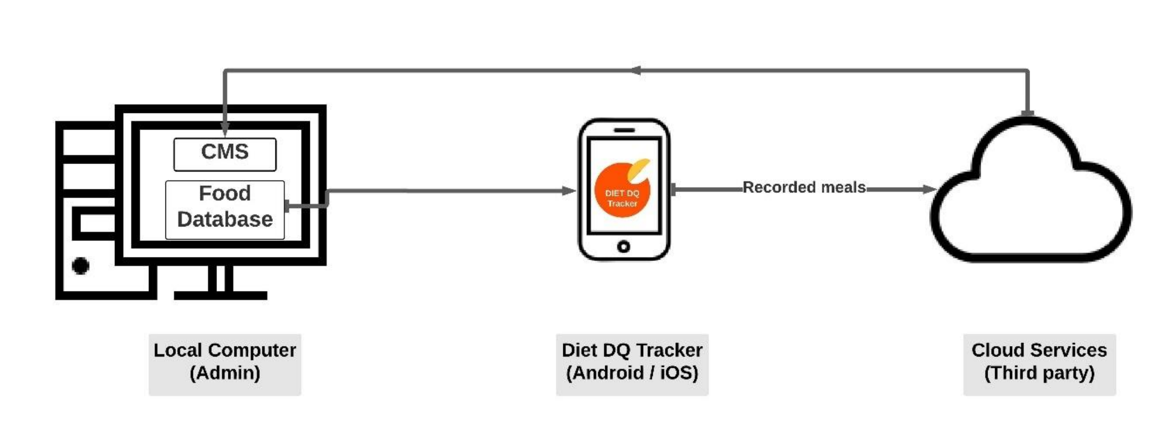


Figure 3.1 : Diet DQ Tracker architecture

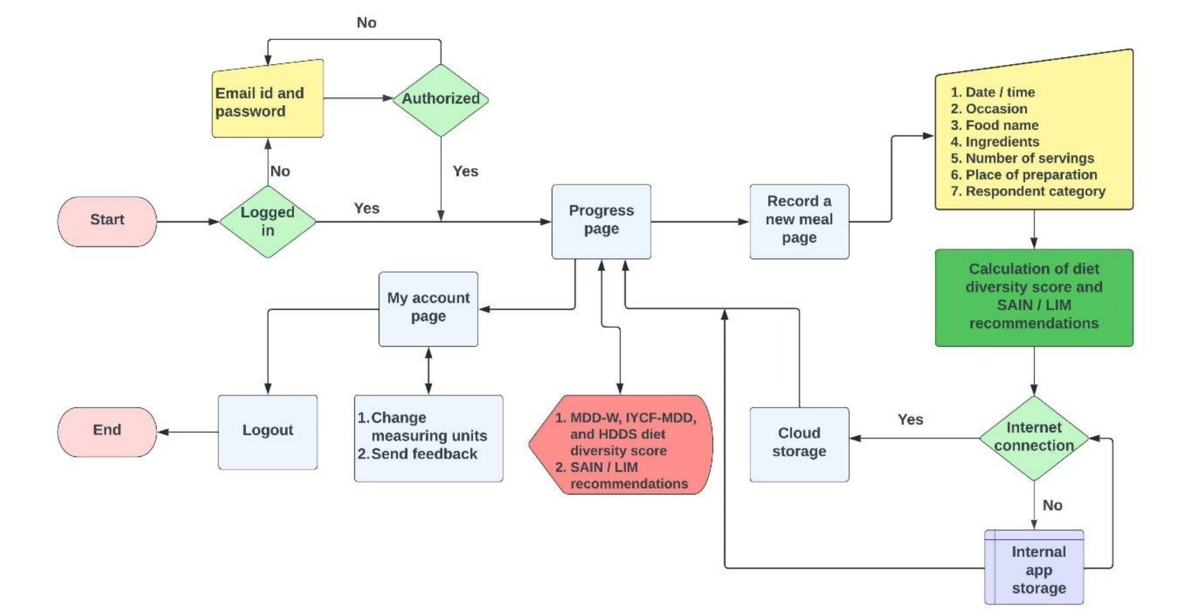


Figure 3.2 : Diet DQ Tracker algorithm framework

If the user is already logged in upon app launch, the algorithm would direct them to the progress page. The application would require a new user to manually enter their authorised email address and password. Users can view their MDD-W, IYCF-MDD, HDDS diet diversity scores and SAIN/LIM recommendations from the progress page. In order to record a new meal user would have to manually enter the date/time, occasion, food name, ingredients, number of servings, place of preparation, and respondent category. After inputting all required meal characteristics, the algorithm will calculate the diet diversity scores and SAIN/LIM recommendations (formulas 1 to 4 in section 3.2.2) using a predefined process based on the respective indicator guidelines. Following the data entry and calculation of the score, data would be transferred to a third-party cloud storage in the presence of the internet; otherwise, it would be stored in the application's internal storage. On the progress page, users can view the data input (meal characteristics) and data output (score achieved) in real time. From the 'Progress' page, users can access 'My account' to change the food quantity measuring units, provide feedback to the research team, and logout of the application.

3.2.4 Food database

A comprehensive database of foods and beverages from around the world linked to the application reduces the effort, time, and resources required for data collection. The automated process of coding and score calculation empowered by the food database generates the output results simultaneously and reduces the need of interviewer training for data collection. USDA’s Food and Nutrient Database for Dietary Studies (FNDDS; 2017 - 2018), Laos’s ASEAN food composition database (electronic version; 2014-01-01), and Ethiopia’s food composition table for use in Ethiopia Part III (1968 - 1997) were used as the starting point of ‘Diet DQ Tracker’ food database. The inclusion of a wide range of macronutrients, micronutrients, and other food components is the principal determinant for using the national food composition databases. The USDA, Laos, and Ethiopian database contains 7083, 619 and 1075 foods respectively. Currently, the app’s food database contains 8777 food products, both raw and cooked (steamed, boiled, roasted, fried etc.), from a variety of categories such as cereals, starchy roots and tubers, legumes, nuts and seeds, vegetables, fruits, egg, dairy, fat and oil, sugar, condiments and spices, snack foods (commercially processed and packed), fast foods (franchise foods), mixed food dishes, and alcoholic/non-alcoholic beverages. Nutritional values for energy, protein, fibre, calcium, iron, vitamin c, vitamin d, added sugars, saturated fatty acids and sodium are provided per 100 grams of food in the database. For Laotian and Ethiopian databases, the values of any missing nutrients were gathered from verified sources.

3.2.5 Content management system

The Content Management System (CMS) manages the increasing digital content collected from the users and National food composition tables. The CMS aids in the long-term cost-effective transition from a physical library to a hybrid of physical and digital libraries. An ideal CMS preserves, organises, and disseminates both locally created and externally collected data, along with their associated metadata (Amato et al., 2004). It is a desktop software that is used to manage the development and alteration of digital content from the smartphone app. Implementing the CMS with ‘Diet DQ Tracker’ increases the information accuracy, flexibility, and improves system management at a lower maintenance cost. The CMS empowers the global admin from research team with complete access to detailed information. Thus, the global admin is entitled with the ability to form local admins, representing the end-users of a specific region. Local admins are assigned auto-generated codes from the CMS as their unique identifier, specifying their region of administration. Global admins are in power of granting CMS access to local admins and end-users. The ‘CODES’ tab of global admin’s CMS version is used to manage local admins. Login account of end users are set up by global admin or local admin (if access granted by global admin) in the CMS by entering the end-user’s name, birth year, and email id, followed by assigning a password for ‘Diet DQ Tracker’ app account. Following the account creation, these details are shared with end-users, who can log into their accounts via the ‘Diet DQ Tracker’ app on their smartphones to record and save their dietary data in a central location accessible to global or local admins. End-users can access their desktop-based CMS account from the same app account, if a global or local admin grants permission. The login details of the end-users can be accessed and modified by global or local admin from ‘USERS’ tab of their CMS version. All CMS users can access the 'Diet DQ' tab, which has three additional tabs, including ‘Meals added’, ‘Food list’, and ‘Ingredients’. Each row in the ‘Meals added’ tab is a unique entry which contains all the information on ‘user’, ‘local admin’, ‘mealtime’, ‘occasion’, ‘food name’, ‘serving’, ‘category’, and ‘prepared at’ recorded in the app, along with MDD-W, IYCF-MDD, and HDDS scores generated from this meal entry. All food items and beverages in the app database are present in the 'Food List' tab. The ‘Food List’ tab provides information on the nutrient composition and food group categories according to different diet diversity indicators. All data stored in the CMS can be exported as an external file for further analysis.

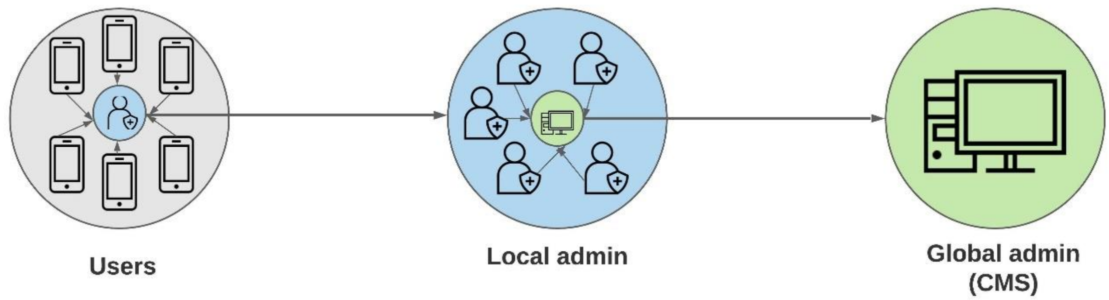


Figure 3.3: Diet DQ Tracker Network

3.3 Results

'Diet DQ Tracker' is developed to help collect dietary information in an easy-to-use manner by overcoming the limitations imposed by traditional methodologies. The application has been developed over the course of 11 months with funding from the International Fund for Agricultural Development (IFAD). The functional flow chart for the 'Diet DQ Tracker' mechanism is visualized in Figure 3.4. The user interface comprises of eight categories: 'Login', 'My account', 'Progress', 'Recommendations', 'Record a new meal', 'Add a new food', 'Repeat previous food', and 'Add ingredient'. Figure 3.5 (i) and Figure 3.5 (ii) illustrates the screenshots of 'Diet DQ Tracker'. Table 3.1 summarizes the components and functionalities of 'Diet DQ Tracker'.

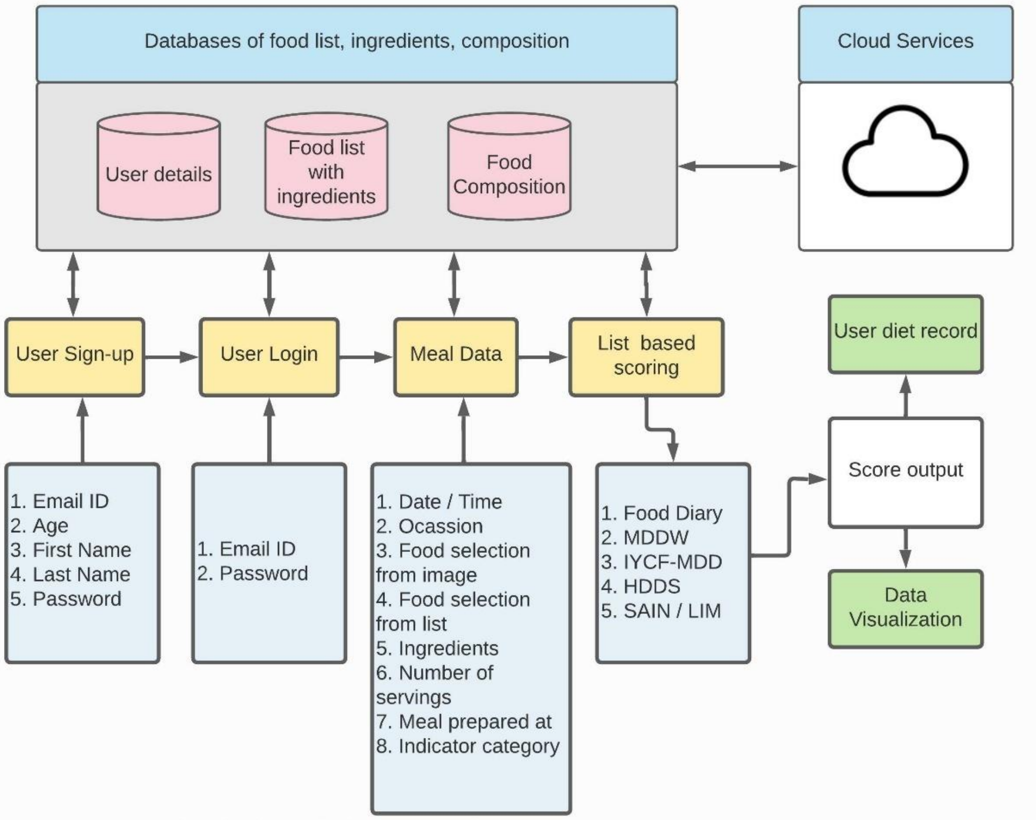
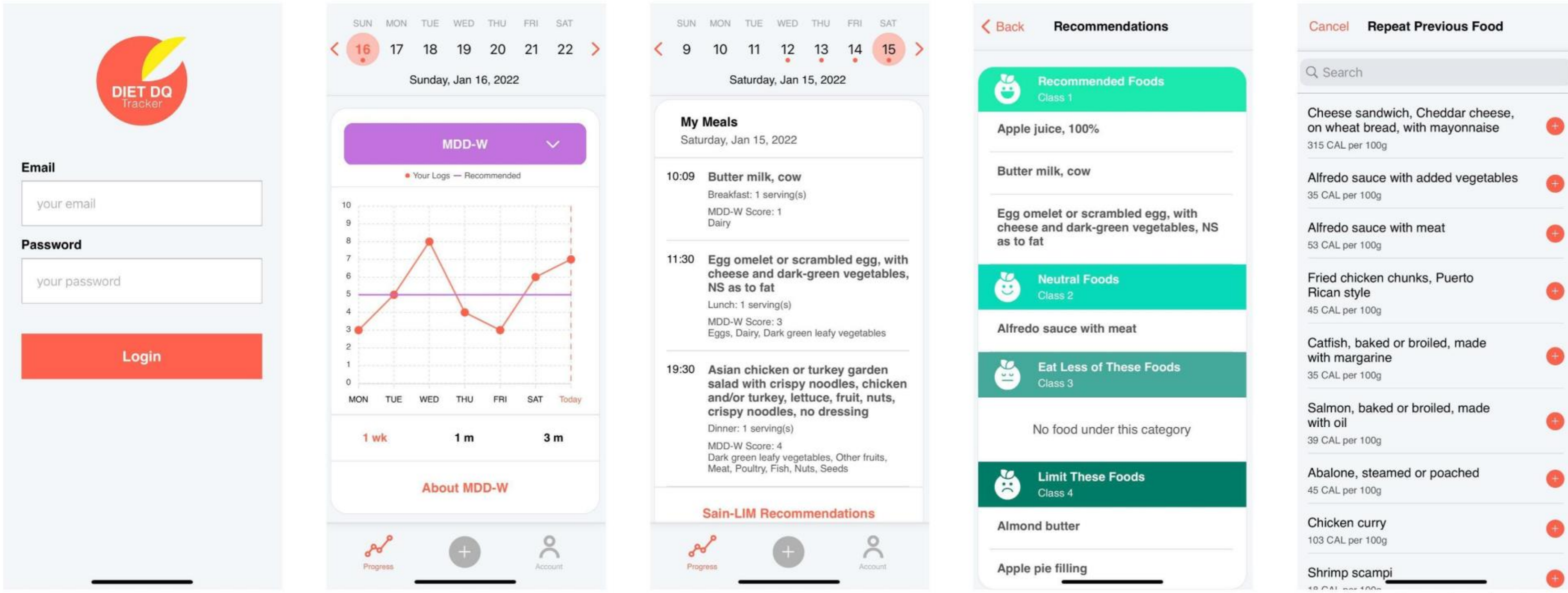


Figure 3.4: Functional chart of Diet DQ Tracker

To begin the process of creating an account, new users must provide their name, birth year, email, and password to their local admin. Once the account has been formed, users can access 'Diet DQ Tracker' via their smartphone by entering their designated email address and password on the log-in page of the app. After logging in, user lands on the progress page. On the progress page, the default date at the top is set to current date. However, users can view their progress on any previous date by changing the pre-set default date. Beneath the date, progress page displays diet diversity scores per week, month, and three months in the form of a line chart, followed by basic indicator information after selecting one of the MDD-W, IYCF-MDD, or HDDS dietary diversity indicators. Below the line chart, a list of foods consumed on that date is displayed under 'My meals', along with other dietary data such as meal occasion, serving size, diet diversity score, and food groups. The SAIN, LIM recommendations of foods consumed in the last week can be accessed by clicking on 'SAIN, LIM Recommendations', which will take users to the recommendation page. On the recommendation page, food items and beverages consumed are divided into four classes based on the SAIN, LIM score: ‘Recommended foods (Class 1)’, ‘Neutral foods (Class 2)’, ‘Eat less of these foods (Class 3)’, and ‘Limit these foods (Class 4)’. At the bottom of the progress page, users can click on the ‘+’ button and the ‘Account’ button to ‘Record a new meal’ and move to ‘My account’ page respectively. On ‘My account page’, users can view their account details, send feedback to the global admin, and sign out of the application.

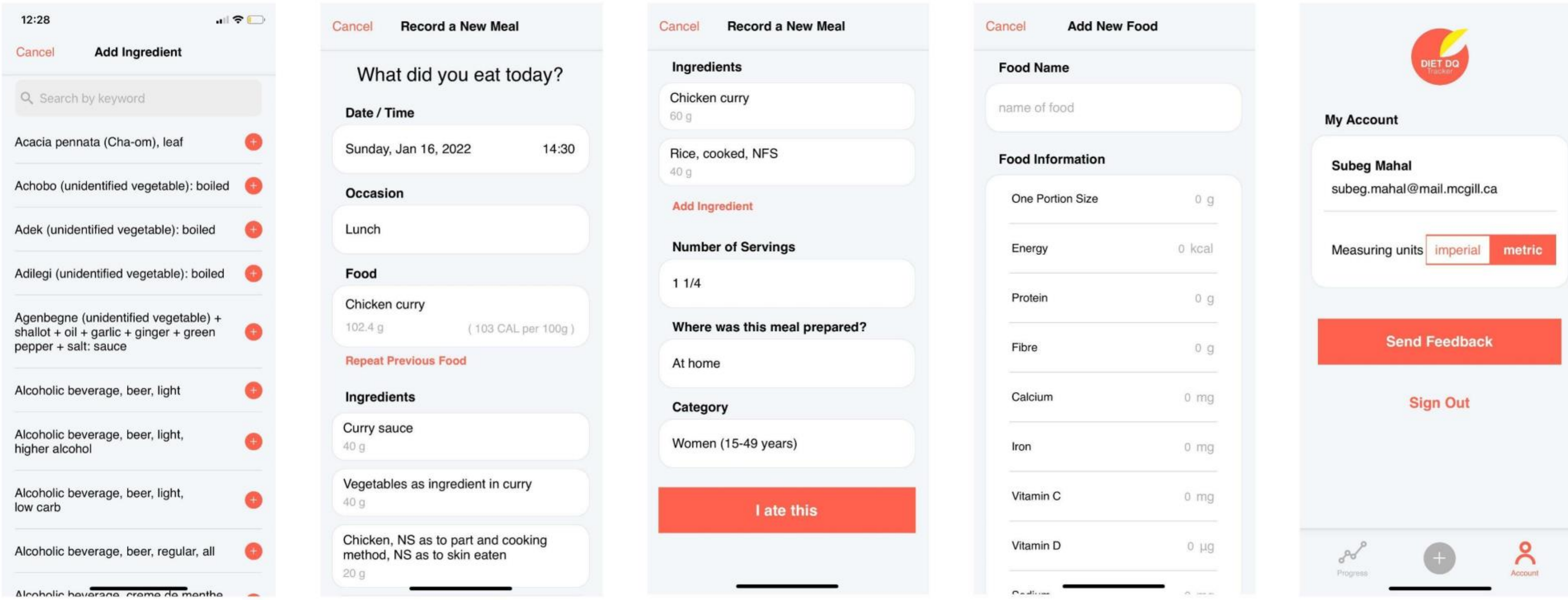
The users begin the dietary recording on the ‘Record a new meal’ page by selecting the meal’s date/time and occasion. By default, the date and time fields for recording meals are set to the current date and time. Clicking on it, however, will allow the user to enter a meal for any previous date or time. After that, user clicks on ‘Select occasion’ to record the meal occasion amongst: ‘Breakfast’, ‘Lunch’, ‘Dinner’, and ‘Snack’. Following that, the user clicks on the ‘Food item’ to record the food name and moves to the ‘Add Food’ page to enter the food or beverage consumed via the search-as-you-type text box. As soon as the user selects the food consumed, they need to enter the number of standard servings of that food item. After entering the number of servings, user needs to specify the place of preparation of food, such as: ‘At home’, ‘At a restaurant’, and ‘Other’. This is followed by selecting the category of user that consumed the food, such as: Children (6-23 months), Women (15-49 years), and Household to record the meal for IYCF-MDD, MDD-W, and HDDS, respectively. In case of IYCF-MDD, ‘user’ refers to the mother or caretaker of the child. After entering all the necessary details, user clicks on ‘I ate this’ button at bottom of the page to save the food consumed in the app database and update the dietary feedback on the progress page.

When food consumed is not present in the app database, the user can click on ‘New Food’ at bottom of the ‘Add Food’ page to access the ‘Add new food’ page. This page requests the food’s name and additional information such as portion size and associated energy, protein, fiber, calcium, iron, vitamin c, vitamin d, sodium, saturated fatty acid, and sugar content. To save this new food, the user clicks on ‘Add new food’ at the bottom, and this new food is saved in user’s local database in the app. Likewise, users can add new ingredients to the food consumed. The global admin checks the details of new food or ingredient, and finally updates the food database for all users. Additionally, ‘Diet DQ Tracker’ saves the previous food names consumed frequently by the user and provides the option to repeat it on the ‘Record a new meal’ page.



Login page | Progress page (i) | Progress page (ii) | Recommendation page | Repeat previous food page

Figure 3.5 (i) : Screenshots of Diet DQ Tracker



Add ingredient page | Record a new meal page (i) | Record a new meal page (ii) | Add new food page | Log out page

Figure 3.5 (ii) : Screenshots of Diet DQ Tracker

TABLE 3.1: Components and functionalities of 'Diet DQ Tracker'

	Components of 'Diet DQ Tracker'	Description of functionalities
1.	'Progress' page	• To view the progress of the user by selecting a date • To view the graphical representation of diet diversity scores by selecting 'MDD-W', 'IYCF-MDD', or 'HDDS' • To view the visual representation over one week, one month, or three months by selecting '1 wk', '1 m', or '3 m' • To view the background information of indicators by clicking on 'About MDD-W', 'About IYCF-MDD', or 'About HDDS' • To view the meals consumed on the selected date by scrolling down to 'My meals' • To view the SAIN, LIM recommendations of foods consumed over the past week, by selecting 'SAIN-LIM Recommendations'
2.	'Record a new meal' page	• To specify the date and time of meal consumption by clicking on pre-set Date/ Time • To specify the occasion of meal consumption (Breakfast, Lunch, Dinner, and Snack) by clicking on 'Select occasion' • To specify the food name by using the search-as-you-type box after clicking on 'Food item' • To specify the food name from food items frequently consumed by the user by clicking on 'Repeat previous food' • To add a new food to the database by clicking on 'Add new food' at the bottom of 'Add Food' page • To add ingredients to the selected food item by clicking on 'Add ingredient' • To specify the number of servings of the food item by clicking on 'Select number of servings' • To specify the place of meal preparation (At home, At a restaurant, Other) by clicking on 'select meal prepared at' • To specify the category of user (Children, Women, or Household) who consumed the meal by clicking on 'Select your category' • To upload the data by clicking on 'I ate this'
3.	'My Account' page	• To change the units of food portion size on the 'Record a new meal' page from imperial to metric by clicking on 'Measuring units' • To send the feedback on any issue/ problem/ or suggestion to the research team by clicking on 'Send Feedback' • To sign out of the application by clicking on 'Sign Out'

3.4 Discussion

3.4.1 Principal considerations

Automating the collection of food consumption data, coding of foods and portion sizes, and the facilitation of accurate self-completion using visual cues for measurement guides and embedded standards are some of the new technologies that are being used in the field (Cade, 2017; Willett, 2012). The purpose of this study is to introduce the design and development of 'Diet DQ Tracker', a smartphone application that tends to augment dietary assessment in Nutrition Sensitive Agriculture by replacing conventional methodology of interviewer-administered questionnaire with a robust self-administered smart phone application consisting of comprehensive food database. In addition to reducing the workload of the researcher, 'Diet DQ Tracker' probes different aspects of meal intake from users in their own time. The app widens the geographic reach of data collection by cost and time-effective methodology. 'Diet DQ Tracker's features include real-time meal recording from a list of thousands of pre-defined foods and beverages, personalized dietary diversity feedback, and recommendations based on SAIN, LIM nutrient profiling system. All meal entries of a particular date are analyzed and visualized collectively, followed by permanent cloud storage that can be retrieved via CMS. Throughout the development process, we struck a balance between the researcher's desire to collect detailed and accurate dietary assessment data and the user's desire to spend as little time as possible with the tool. Considering the time spent while collecting dietary data by the 'Automated Multiple Pass Method' (AMPM) of nutrition survey, the research team opted not to use this traditional methodology. However, AMPM's strengths are partially being fulfilled in the app by features such as repeat previous foods, detailed food entry by a search-as-you-type textbox, probing for time and occasion, and lastly, final review before submitting the food entry.

3.4.2 Related work

Prior studies have found a high level of agreement between traditional and modern approaches, with the latter being preferred by most participants (Sharp & Allman-Farinelli, 2014). A feasibility study of a commercial smartphone app compared a 4-day food diary completed by a modified version of ‘Easy Diet Diary’ with two 24-h dietary recalls performed during the same week (Ambrosini et al., 2018). The app was preferred by 50 adults (82 per cent of whom were women) for completing 24-h dietary recalls. The average energy consumption discrepancy between the traditional method and the smartphone app was 268 kJ/d, and most of the limits of agreement were within the acceptable range. In another validation study, the ‘Eat and Track’ (‘EaT’) app was used to track participant’s food and beverage intake for three days, and the results were compared with three dietitian-administered 24-h recall interviews conducted on the same days as the reference method (Wellard-Cole et al., 2019). Although the median energy intake was significantly different between the two methods, the ‘EaT’ app had acceptable agreement for the majority of nutrient densities at the group level. Evaluation study of ‘e-CA’, an electronic mobile-based food record had good agreement with 24-h dietary recalls but confirmed the complexity of determining the portion sizes (Bucher Della Torre et al., 2017). Another validation study comparing mobile phone app ‘e-DIA’ with 24-h dietary recall found no significant differences in mean energy or nutrient intakes between the two methods (Rangan et al., 2015). In another validation study of ‘My meal mate’, a weight loss app, revealed wide limits of agreement with 24-h recall at individual level, but demonstrated great potential as a group-level dietary assessment tool (Carter et al., 2013).

3.4.3 Strength and limitations

‘Diet DQ Tracker’s primary strength is that it is the first smartphone application designed to collect data for globally recognized diet diversity indicators, such as MDD-W, IYCF-MDD, and HDDS used in resource-poor community settings. Unlike traditional methods, the app is designed to collect dietary information immediately after consumption and thus does not rely on human memory. The application incorporates a novel and extensive food composition database that generates the score for indicators and suggests the food consumption by the SAIN, LIM nutrient profiling system. The desktop-based CMS application enables the researcher to add, delete, and edit food items and their associated nutrient content in response to user demand and recent food composition table updates. The application serves three distinct target audiences (women of reproductive age, infants and children under the age of two, and households, including all members) and is user-friendly across a broader range of the population. The application gives real-time dietary feedback by computing the scores in backend (without additional coding). The data collected by the app is automatically stored in the cloud and represented in the CMS application for further analysis.

‘Diet DQ Tracker’ has some limitations as well, including the user burden associated with recording dietary data from a vast list of food items and beverages. While the user is presented with a search-as-you-type text box, navigating through the vast food and beverage list can be challenging. However, the presence of the 'Repeat previous food' function alleviates some of this burden by prioritizing a user’s list of frequently consumed food items. Commercial apps may have a concise list of food items, but this is likely to exclude foods that are not frequently consumed by the population. Additionally, they are likely to result in less precise food records and nutrient intake calculations (Rangan et al., 2015). Considering the app’s complexity in terms of indicators, food database, and score calculation, challenges encountered while collaborating with an external software company included online video meetings (due to COVID-19 pandemic), communication, and effective project management. A few of these issues have been identified frequently when nutrition researchers team up with external software development companies. Furthermore, keeping an up-to-date database of food compositions will be a continuous challenge, given the frequency with which food and beverage manufacturers reinvent products or introduce new ones in the market. Another limitation of the app is that it has not been validated against traditional or biological methodologies for collecting dietary data.

3.4.4 Future work

The selection of biological methods like doubly labelled water (DLW) as a reference method for the validation of diet assessment app, may be challenging due to the complexity, cost implications, and requirements of highly controlled settings (Ahn et al., 2019). Additionally, traditional methodologies have inherent limitations that effect the validation of diet assessment, when compared with mobile-based apps (Ahn et al., 2019). However, the performance of mobile-based apps in comparison to traditional and biological methods, needs to be investigated through a detailed analysis of data collected by both methodologies, on overlapping days. A new feature will be added that incorporates food recognition by taking a picture of the food item, using the mobile camera. The app will be intelligent enough to recognize the food and provide the real-time dietary feedback. The app’s database stored in cloud will be updated with hundreds of images of individual food items aiding the algorithm in food identification. Additionally, food composition tables containing a variety of foods representing multiple nationalities will be added on a regular basis to strengthen the database. The system will be maintained periodically to ensure that food database remains up to date.

3.5 Conclusion

'Diet DQ Tracker' is self-administered app designed to collect data on meal intake from user's phone, right after the consumption. Thus, allowing lesser respondent-researcher burden as in retrospective methods (dietary recalls), more cost- and time-efficient data collection, a wider geographic reach, and greater respondent acceptability. The app holds on prime strengths of AMPM method to some extent and alleviates the limitations of traditional methodologies. The application incorporates a novel and extensive food composition database that will be updated on a regular basis to include foods from multiple nationalities. 'Diet DQ Tracker's validation study with reference to established traditional methodologies will soon require detailed analysis of data collected via both methods, to evaluate the app performance, strengths, and limitations.

FOREWORD TO CHAPTER IV

In Chapter III, design, development, and key features of the 'Diet DQ Tracker' were demonstrated. In Chapter IV, the performance and comparative validity of the smartphone application with reference to an interviewer-administered 24-h dietary recall was determined. Additionally, data was gathered via a user feedback survey to ascertain user experiences and opinions regarding the usability of 'Diet DQ Tracker' in comparison to traditional methodology.

CHAPTER IV

COMPARATIVE VALIDITY OF THE 'DIET DQ TRACKER' SMARTPHONE APPLICATION AND 24-HOUR DIETARY RECALL METHODS FOR DIETARY DIVERSITY MONITORING

Abstract

Background: Enhancing data collection and analysis methodologies is critical for ensuring effective dietary and nutritional surveillance. Access to smartphones and internet is increasing exponentially across the globe and among various sociodemographic and age groups. Therefore, the use of self-administered smartphone applications to collect dietary data has become irrefutable, with the critical question being data's reliability and accuracy in comparison to traditional methodology.

Objective: The purpose of this study was to establish a preliminary basis for a more elaborate study on the acceptability, feasibility, and relative validity of the 'Diet DQ Tracker' by 3-day self-administered real-time food recording in comparison to the traditional methodology of interviewer-administered 24-h dietary recall.

Methodology: Twenty respondents (10 females, and 10 males) familiar with dietary surveys were requested to be part of the preliminary study to collect the preliminary dietary data for MDD-W and HDDS via 'Diet DQ Tracker' for three consecutive days and completed one 24-h interviewer-administered telephone recall during this 3-day study period. Following the dietary data collection via both methodologies, respondents were asked to complete a user feedback survey questionnaire about their experience with the app and 24-h recall, including their preferred methodology, convenience, ease of use, time consumption, and learnability.

Results: The p-value for mean MDD-W and HDDS diet diversity scores at group level were 0.8501 and 0.7651, respectively, indicating no significant difference between the two methodologies. The fact that 100% of respondents preferred to provide their dietary information via ‘Diet DQ Tracker’ demonstrates the app’s acceptability over interviewer-administered dietary recalls.

Conclusion: ‘Diet DQ Tracker’ is a promising tool facilitating dietary data collection for research by reducing the perceived workload, effort, time, and resource utilization. Overall, the performance of the app was highly satisfactory. However, further research will be warranted to investigate different sources of variations between both methodologies.

Keywords : Relative validity, dietary assessment, smartphone, MDD-W, HDDS

4.1 Introduction

Standardized and validated methods for diet and nutrition assessment are a prerequisite for consistent nutrition monitoring and evaluation at the national, regional, and international levels in public health nutrition (Gibson, 2005; Willett, 2012). To ensure effective dietary and nutritional surveillance, it is critical to improve available dietary information, by enhancing data collection and analysis methodologies. This improvement is possible by employing standardized modern methodologies and protocols for collecting food consumption data (E.F.S. Authority, 2009). There are several examples of modern technologies being used to measure dietary intakes in intervention studies, but fewer examples of large-scale nutrition surveys and epidemiological studies (Conrad & Nöthlings, 2017). To date, most of the latter large-scale studies continue conducting surveys using traditional methodologies, administered by an interviewer on paper or via computer (Amoutzopoulos et al., 2018). Traditional methods of collecting dietary data, such as multiple 24-hour (24-h) dietary recalls and food diaries, can be impractical for large-scale studies as they usually require significant resources and time-consuming manual coding (Carter et al., 2015). Epidemiological studies make use of food frequency questionnaires (FFQs), which are simple to administer and possess less respondent burden (Carter et al., 2015). However, measurement errors in FFQs can occur as a result of a lack of precision in portion sizes, a lack of information about food preparation, a limited list of food items, and the possibility of classifying participants incorrectly based on their food intake (Bingham et al., 2003; Schatzkin et al., 2009). Multiple 24-h dietary recalls accurately reflect daily dietary intake and have less reporting bias for energy and protein intakes when compared to FFQs using biomarker measures (Subar et al., 2003). However, in dietary recalls, foods consumed are often forgotten, and foods reported are frequently not those which were consumed. This selective recall appears to be influenced by desirability perceptions (Willett, 2012). Additionally, bias can be introduced while probing for incomplete information, while interpreting the recalled information, or while discarding the doubtful or unusual data (Willett, 2012).

The mode of delivery for effective participation and the reduction of measurement errors from collecting high-quality data is critical to the success of nutrition survey methodology (Amoutzopoulos et al., 2018). In population studies, technological innovations appear to be promising for identifying and mitigating measurement errors in dietary assessment (Conrad & Nöthlings, 2017). Recent technological advancements provide opportunities to improve the objectivity of assessment measures by improving data collection efficiency, data quality, dietary data coding and processing, response rates, researcher and respondent burden, geographical reach and cost-time requirements (Long et al., 2013). Modern technologies include web-based tools and mobile device applications that automate the food consumption data collection, coding of foods consumed, portion sizes, and data analysis. Handheld technology, such as mobile phones, offers the convenience of real-time food recording (Carter et al., 2013). With the advancement of technology, smartphone's computational capabilities have increased, enabling them to connect to the internet and run their entire operating system. A smartphone application that allows users to track their diets provides a convenient and cost-effective method for dietary data collection as compared to traditional methodologies (Carter et al., 2013).

In literature, a number of smartphone applications have been developed and validated against interviewer-administered 24-h dietary recall (Ahn et al., 2019; Bucher Della Torre et al., 2017; Carter et al., 2013; Rangan et al., 2015; Wellard-Cole et al., 2019). The research team at McGill University had developed 'Diet DQ Tracker', the first self-administered smartphone application designed for collecting and evaluating dietary data for diet diversity indicators used at population level. The purpose of this study was to determine the acceptability, feasibility, and relative validity of the 'Diet DQ Tracker' by self-administered real-time food recording in comparison to traditional methodology of interviewer-administered 24-h dietary recall. We compare and contrast the mean diet diversity score (DDS) at group level with both methodologies and report on user preferences and experiences. We hypothesized that the DDS would be moderately consistent between the two methodologies.

4.2 Material and methods

The 'Diet DQ Tracker' is a dietary data collection application compatible with iOS and Android devices. The primary goal of this application was to replace the traditional methods of dietary data collection, such as interviewer-administered 24-h dietary recall via paper questionnaires or on tablets. The 'Diet DQ Tracker' is an intuitive tool with a robust food database and unique features that overcome the limitations of traditional methodologies by effective data collection, followed by automated upload on cloud services, thereby saving time, resources, and effort.

4.2.1 Development and description of 'Diet DQ Tracker'

To the best of our knowledge, 'Diet DQ Tracker' is the first self-administered smartphone application designed to collect dietary data for diet diversity indicators at the individual and household level, using a database of thousands of foods and beverages structured by indicator-based food groups. At the individual level, the application collected data on Minimum Dietary Diversity for Women (MDD-W) from women of reproductive age (18-49 years) (FAO, 2016) and at the household level, data was collected for Household Dietary Diversity Score (HDDS) (Swindale & Bilinsky, 2006). One of the application's primary features was the real-time computation and visual representation of these diet diversity indicator scores right after recording of food items. The MDD-W and HDDS scores calculated in the app ranged from 0 to 10 and 0 to 12, respectively. The DDS was calculated using the food groups consumed by individuals or household over the last 24 hours from MDD-W and HDDS, respectively. Additionally, the app provided SAIN, LIM recommendations for all food items or beverages consumed during the study period. These recommendations were based on the food's healthiness or unhealthiness index (Darmon et al., 2009). Energy and six beneficial nutrients, including protein, fiber, calcium, iron, vitamin C, and vitamin D, were used to calculate the healthiness index of food items. On the other hand, the unhealthiness index was calculated using three nutrients that should be restricted in food items which are sodium, sugar, and saturated fat. After computation, the SAIN, LIM model categorized food items into one of four classes: 'Recommended foods' (Class 1), 'Neutral foods' (Class 2), 'Eat less of these foods' (Class 3), or 'Limit these foods' (Class 4) (Darmon et al., 2009).

While recording a meal with 'Diet DQ Tracker', the users followed a seven-step process : (1) Specifying the date and time of each meal consumed during the day; (2) Defining the 'Occasion' of meal consumption amongst 'Breakfast', 'Lunch', 'Dinner', and 'Snack'; (3) Typing and selecting the name of the food/ beverage consumed from the search-as-you-type textbox; (4) Adding ingredients (if any) to the standard recipe of food item already present in the database; (5) Defining the number of servings in relation to the standard portion size of food item; (6) Selecting the location of meal preparation amongst ‘Home’, ‘Restaurant’, and ‘Other’; (7) Selecting the respondent/ user category amongst 'Children (6-23 months)’, 'Women (15-49 years)’, and 'Household'.

A comprehensive database of foods and beverages from USDA’s Food and Nutrient Database for Dietary Studies (FNDDS; 2017 - 2018), Laos’s ASEAN food composition database (electronic version; 2014-01-01), and Ethiopia’s food composition table for use in Ethiopia Part III (1968 - 1997) had augmented the ‘Diet DQ Tracker’ food database with 7083, 619, and 1075 foods respectively. A desktop-based Content Management System (CMS) application was developed and connected with the cloud services to update the ‘Diet DQ Tracker’ food database and access the dietary data collected from the app users. CMS empowered the research team to create user accounts by specifying their name, email address, and password. In order for users to install the application and log in, the research team provided an installation link and login credentials. The app was installed over the internet, and the food database was automatically imported from the cloud services. The food database was stored permanently in the app memory, enabling the ‘Diet DQ Tracker’ to collect dietary data even in the absence of internet connection. In this case, data collected was stored temporarily in the app memory until the availability of internet connection for secure uploading to cloud services. The data from the user’s ‘Diet DQ Tracker’ app account was stored and transferred via cloud. This data was accessed by the research team through desktop-based CMS app. CMS enabled the export of collected data in a comma-separated values (CSV) file for in-depth analysis.

4.2.2 Study sample and recruitment

A total of twenty volunteers with good knowledge of dietary survey agreed to participate in the ‘Diet DQ Tracker’s validation study for three consecutive days. They were recruited via phone calls, text messages, and word-of-mouth. Ten female volunteers worked on collecting MDD-W data, and the remaining ten male volunteers focused on collecting HDDS dietary data. Participants were eligible to enroll in the current study if they were aged above 18 years and owned a functional android or iOS smartphone with the internet access. Participants were excluded from the validation study if they couldn’t record their dietary data for three consecutive days on ‘Diet DQ Tracker’, could not participate in one 24-h dietary recall (administered via phone call), could not read and write in English (for using the application), and were on a medically restricted diet.

4.2.3 Procedure

After recruitment, eligible participants were inquired about their full name, email address, and birth year to generate their app account from the CMS application. Following the account generation, app installation link and account login details were shared with the participants. One week prior to the data collection, participants received oral instructions on goals, features, and usage of the 'Diet DQ Tracker'. Since one of the objectives of this validation study was to ascertain the app's usability and learnability, participants received instructions only on app's basic functionalities rather than specific training on app usability. They were given an entire week to understand and learn the procedure of recording food items in the app. If they had any doubts, they could contact the researchers via phone, text, or email.

4.2.3.1 Dietary assessment

To validate the DDS's from self-administered 'Diet DQ Tracker' app against interviewer-administered 24-h dietary recall, dietary data was collected for MDD-W and HDDS via both methodologies.

'Diet DQ Tracker': Participants were instructed to record the food items/ beverages in 'Diet DQ Tracker', right after consumption for three fixed consecutive days (two weekdays and one weekend day). It was acknowledged that the majority of participants were willing to record data on weekends in anticipation of an unannounced 24-h recall during a less busy time period. Participants were reminded daily via text message or phone call for three days to record the meals consumed on the app. Data for HDDS was collected next week, following the MDD-W data collection. While weighing of food items was encouraged to record the number of servings, it was not a mandatory part of the procedure to minimize participant burden. Further, participants were directed to breakdown food recipes into their constituents and add them as single items under the ingredients. This was also the procedure followed during the 24-h recalls. In rare instances where a food item consumed was not included in the food database, participants were instructed to enter the food's name and nutritional information using the 'add new food' feature. All data collected over this three-day period was securely uploaded to cloud services, which was accessible by CMS for detailed analysis.

24-h recall (reference measure): The interviewer-administered 24-h recall method was chosen as a reference measure to minimize the correlation errors between the two methodologies, which is consistent with other validation studies. Participants were randomly contacted for an unannounced dietary recall throughout the three-day study period. However, an appropriate calling time for recall was established before the commencement of dietary assessment, at the convenience of participants. To standardize the recall process, questionnaires were developed for both MDD-W and HDDS. These questionnaires consisted of open-ended questions that were asked in chronological order. The dietary recall was administered via phone call using pen and paper forums. To collect data from both methodologies on an overlapping day, 24-h recall was administered the next day, capturing data for the same day the app was used. Participants were strongly advised against relying on 'Diet DQ Tracker's recorded data for the previous day, to aid in remembering the food items consumed, during the 24-h recall.

4.2.3.2 Participant feedback on dietary assessments

Following data collection via both methodologies, participants were asked to complete a user feedback survey questionnaire about their experience with the app and 24-h recall, including their preferred methodology, convenience, ease of use, time consumption, and learnability. Participants were asked to respond on statements using a 5-point Likert scale (strongly agree, agree, neutral, disagree, or strongly disagree). Additionally, respondents were provided with an optional comment section at the end of the survey to record their comments, suggestions, requirements, or experiences on the app in order to contribute to its improvement.

4.2.4 Data processing and statistical analysis

Throughout the data collection, 'Diet DQ Tracker' entries were verified in the CMS by end of the day. The following day, participants were contacted to clarify any obvious inconsistencies, such as incorrect number of servings, conflicting time and eating occasions, and information on the newly added foods in the database. However, to obtain an accurate indication of the app's relative validity, only minor changes were made to the data, keeping it as unaltered as possible. Dietary data from 24-h recall questionnaires was recorded on paper forums during the phone call. Following the recall, data was observed critically, and DDS's were calculated manually by assigning the food groups to different constituents of food items. This data was digitalized and stored manually by the researchers in Microsoft word and excel spreadsheets to compare and analyze with the 'Diet DQ Tracker'.

The aim of statistical analysis was to figure out the limit of agreement and observe the significant difference in dietary scores generated by both methodologies. We compared the DDS of every individual respondent generated by 'Diet DQ Tracker', with the DDS of the same day for the same respondent, generated manually by a 24-h recall. Therefore, the DDS's from these paired observations were compared by Wilcoxon sign-rank test. MDD-W assigns a score out of ten, and HDDS assigns a score out of twelve; therefore, statistical analysis for both groups of respondents was conducted separately. The p-value generated from DDS's by both methodologies were represented separately by a line graph, boxplot, and stacked bar graph.

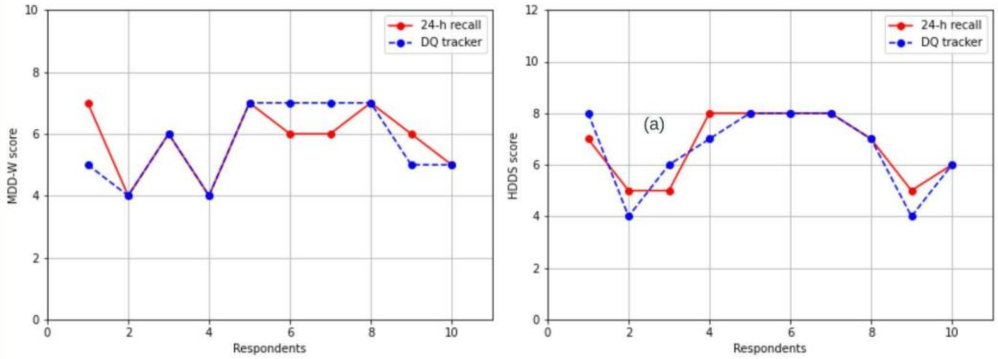
4.3 Results

Twenty participants, ten female and ten male, volunteered to participate in 'Diet DQ Tracker's validation study. Amongst them, seventeen participants (85%) aged between 18-35 years and three participants (15%) aged between 36-50 years. Dietary data via 'Diet DQ Tracker' was collected for 3-consecutive days over a two-week period. In this 3-days period, participants were contacted randomly for one 24-h interviewer-administered telephone recall. Female participant's MDD-W data was collected over two weekdays and one weekend day during the first week, and the male participant's HDDS data was collected on the same days the following week. Following the collection of dietary data, participants were contacted via text messages and phone calls to fill out an offline participant feedback survey on their experiences using the app and undertaking a recall.

4.3.1 Comparison of DDS's from 'Diet DQ Tracker' and 24-h recall

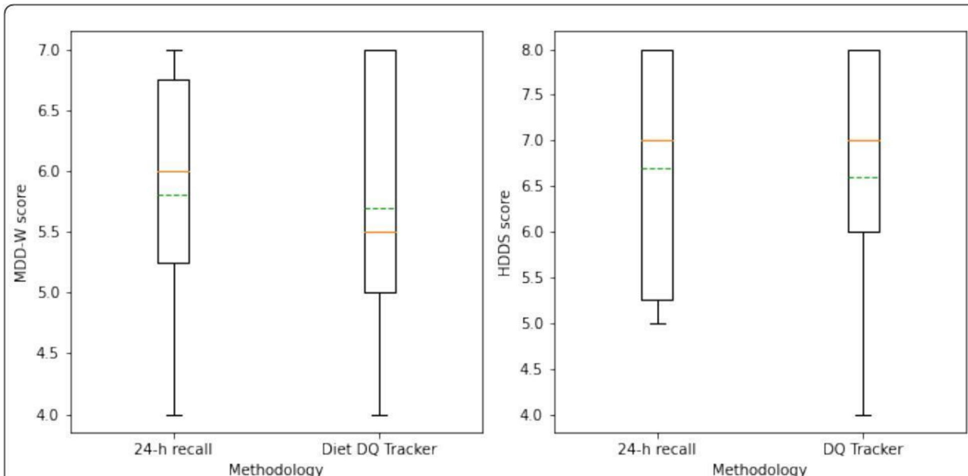
The p-value for MDD-W and HDDS DDS was 0.8501 and 0.7651, respectively, indicating no significant difference between the two methodologies. Respondent wise DDS for MDD-W by both 'Diet DQ Tracker' and 24-h recall is shown in Figure 4.1 (a). Six female respondents achieved the same MDD-W score via both methodologies. Amongst the remaining respondents, two had a lower score, and two had a higher MDD-W score on the 'Diet DQ Tracker' in comparison with 24-h recall. In Figure 4.1 (b), five male respondents had the same HDDS score via both methodologies. In contrast, on comparison with 24-h recall, three respondents had a lower HDDS score on 'Diet DQ Tracker', while two had a higher HDDS score.

The minimum, first quartile, mean, median, third quartile and maximum of DDS's of MDD-W and HDDS, for 'Diet DQ Tracker' and 24-h recall, were represented in Box and Whisker plots in Figure 4.2. The figures 4.3(a) and 4.3(b) illustrate the variation in the contribution of food groups to the mean MDD-W and HDDS scores, respectively, using both methodologies. The minimal difference in food group's consumption demonstrates no significant variation between the data collected via both methodologies in this validation study.



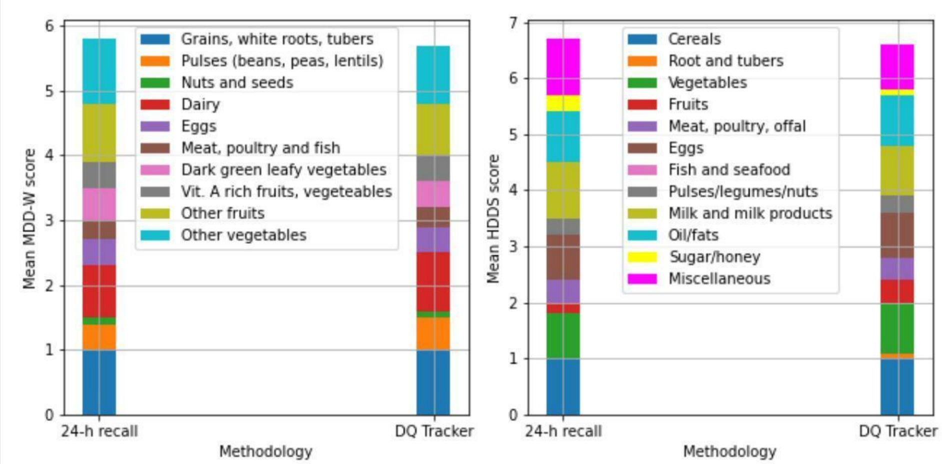
(a) (b)

Figure 4.1: Line chart for (a) MDD-W and (b) HDDS representing DDS generated via 24-h recall and Diet DQ Tracker at individual level



(a) (b)

Figure 4.2: Box and Whisker plot for (a) MDD-W and (b) HDDS representing DDS at group level for '24-h recall' and 'Diet DQ Tracker'



(a) (b)

Figure 4.3: Stacked bar graphs for (a) MDD-W and (b) HDDS representing consumption of different food groups

4.3.2 Participant feedback on 'Diet DQ Tracker' and 24-h recall

Participant feedback on their experience regarding recording data via self-administered 'Diet DQ Tracker' and interviewer-administered 24-h telephone recall has been summarized in Appendix. The majority of participants agreed or strongly agreed that: The Diet DQ app was easy to understand (95%); was easy to use (95%); foods and beverages were recorded on the app right after consumption (55%); and the app had proved to be highly satisfactory (90%). The 'Diet DQ Tracker' app was preferred by all 20 participants over the 24-h recall as it was more convenient, easy to use, less time consuming, portable, and enjoyable to use. In addition, 95% of participants frequently accessed graphic visualizations of their MDD-W and HDDS scores, and 80% accessed SAIN, LIM food consumption recommendations on a regular basis. The graphic visualizations and SAIN, LIM recommendations prompted the consumption of diverse diets and healthy foods in 75% and 80% participants, respectively. The average time spent in recording food and beverages consumed over the course of a day was 8.4 minutes with 'Diet DQ Tracker' and 10.25 minutes with 24-h recall.

4.4 Discussion

This is the first validation study evaluating a self-administered smartphone application designed for diet diversity indicators MDD-W, IYCF-MDD, and HDDS, with interviewer-administered 24-h telephone recall as reference methodology. The purpose of this study was to compare and contrast the DDS's obtained using 'Diet DQ Tracker' and conventional methodology. Additionally, the participant feedback survey elicited their views on the preferred methodology and 'Diet DQ Tracker's usability, acceptability, perceived workload, strengths, and weaknesses.

4.4.1 Dietary assessment

The higher p-values from the Wilcoxon sign-rank test, 0.8501 for MDD-W and 0.7656 for HDDS, emphasized the lack of any significant difference between the two data collection methodologies. The MDD-W and HDDS scores procured from 'Diet DQ Tracker', and 24-h recall had an acceptable level of agreement at the group level. There were slight differences at the individual level which were demonstrated in Figure 4.1. In comparison with 24-h recall, nine out of twenty respondents achieved a different DDS using ‘Diet DQ Tracker’. Eight of them had scores that varied by a single food group, while one had a score that varied by two food groups. The validation study of ‘Intake24’ concluded that food underreporting occurred frequently in interviewer-administered 24-h recalls (Bradley et al., 2016; Rowland et al., 2016). Their examination of two methodologies presupposed that greater the number of food items reported by any methodology, greater is the methodology's accuracy. In a health survey, it was revealed that underreporting by 24-h recalls was 19% in males and 23% in females (Alston et al., 2017). In another study, the rate of underreporting by conventional methodology was 14.8% (Wellard-Cole et al., 2019).

However, in the present study, ‘Diet DQ Tracker’ and interviewer-administered 24-h recalls revealed nearly equal under- and over-reporting of food items. Food groups such as ‘Condiments’, ‘Sugar’, ‘Oil’, and ‘Vegetables’ (added as an ingredient) were mainly under-reported in ‘Diet DQ Tracker’. For example, salt was not recorded when sprinkled on boiled eggs, vegetable oil was not recorded in rice and beans, sugar was not added to coffee, and vegetables like onions, and tomatoes were not recorded as additional ingredients in egg omelet. Since most of the major ingredients were automatically recorded by selecting the standard recipe of food item from the app database, recording of any additional ingredient to recipe was often overlooked by respondents. This led to variation in consumption of food groups (Figure 4.3), and ultimately DDS between both methodologies (Figure 4.2). On the contrary, omission of these food groups was limited in conventional methodology by employing appropriate interviewer probes for commonly forgotten food items. Additionally, in the version of ‘Diet DQ Tracker’ exercised in the present study, respondents had the advantage of reviewing their meals consumed in the last 24 hours, during the telephone recall. The majority of respondents (65%) agreed or strongly agreed with the statement “Meals logged the day before were checked prior to or during the interview administered recall session”. Thereby, only four respondents underreported food items in 24-h dietary recall. Three of the four food items under reported in 24-h recall belonged to the food group ‘Fruits’, and one was from ‘Nuts and Seeds’.

4.4.2 Principal findings

The use of mobile phones to collect dietary data in health research studies is growing rapidly, enabling researchers to collect and respondents to provide data in a less intrusive and burdensome manner. Additionally, they boost respondent interest and participation in the research (Zenk et al., 2011). All these factors result in increased response rates, decreased study attrition, and potentially support in data collection for longer periods of time (Pendergast et al., 2017; Wang et al., 2006). The ‘Diet DQ Tracker’ application was downloaded and installed by respondents on their personal iOS and android smartphones, thus saving the research resources, while increasing the geographic reach of data collection. Access to smartphones and internet is increasing exponentially across the globe and among various sociodemographic and age groups (Touvier et al., 2010). Thus, the use of self-administered smartphone application to collect dietary data has become irrefutable, with the critical question being data’s reliability and accuracy in comparison to traditional methodology, which had good agreement in current study. The fact that 100% of respondents preferred to provide their dietary information via ‘Diet DQ Tracker’ demonstrates the app's acceptability over interviewer-administered dietary recalls. Although the variation in DDS was insignificant in this study, it is believed that limiting the involvement of interviewer in data collection may increase the reporting of food items (Probst et al., 2008).

The flexibility and freedom of respondents to record their dietary data at any time in the day by user-friendly interface of the application was another major reason for preferring ‘Diet DQ Tracker’. In contrast, respondents were reached multiple times for them to report their dietary data via 24-h recall, thus increasing the researcher and respondent burden in conventional methodology. Although respondents were asked to record their food items on the app right after consumption, it was acknowledged that some respondents preferred to record food items at the end of the day. Therefore, 45% of respondents were neutral on the statement, “Foods and beverages were recorded on the app right after consumption”.

The mean time reported by respondent’s in providing their dietary information via dietary recall and ‘Diet DQ Tracker’ was 10.25 minutes, and 8.4 minutes, respectively. Apart from the respondent's time, the researcher spent approximately 22 to 25 minutes, per respondent, on collecting dietary data via telephone recall, categorizing ingredients into respective food groups, and feeding of data into a computer for analysis. Therefore, the total dietary data recording time spent by both the respondent and the interviewer via dietary recall was 32.25 to 35.35 minutes, which is roughly equivalent to a half man-hour. On the contrary, automated process of data collection and cloud storage by employing ‘Diet DQ Tracker’, significantly reduced the researcher burden, since no additional time was required in score calculation and feeding of data. It was deduced that dietary data from 6 respondents could be collected via 'Diet DQ Tracker' in one man-hour, representing a 300 percent increase in the number of respondents. The real-time graphical representation of the DDS and SAIN, LIM recommendations were checked frequently by majority of respondents in the app. This prompted 75% of respondents to consume diverse food groups and 80% of respondents to consume healthy diets.

4.4.3 Limitations and improvements

One major limitation of the present study, typically of validation or comparative studies (Rangan et al., 2015; Touvier et al., 2010), is that recording of food items in ‘Diet DQ Tracker’ may have influenced the interviewer-administered 24-h recall (next day) by reducing memory bias. Additionally, the access of ‘My meals’ on ‘Progress page’ in the app could have helped respondents in recalling food items during the 24-h telephone recall. Majority of participants strongly agreed that ‘My meals’ were checked during the dietary recall. This is one prime reason for reduced duration of 24-h recalls (10.25 minutes) in this study as compared to other validation studies. In validation study of e-DIA, it took 30 minutes to record food items via interviewer-administered 24-h telephone recall (Rangan et al., 2015). To overcome this loophole, ‘My meals’ will be inaccessible to the respondents in the subsequent versions of ‘Diet DQ Tracker’ designed specifically for collecting dietary data in validation study. Another limitation was that this study sought a convenient sample of participants pertaining to the respondent burden and the time required to collect dietary data, which made recruitment difficult. Majority of participants were under the age of 35 and expressed high levels of comfort while using the app on their smartphones. The quality of dietary data collected via smartphone or computer-based dietary assessment tools is directly proportional to the education level (Edwards et al., 2007) and inversely proportional to the age group (Klovning et al., 2009). Therefore, caution is necessary while extrapolating the current findings to the general population. Another constraint was the distribution of weekdays and weekends, which had been defined for convenience in the current validation study to facilitate the respondent availability. The current study does not accurately reflect the distribution of weekdays. Although there is no reason to believe that a more even distribution of weekdays would significantly alter the results of current findings, however, this parameter should be considered and evaluated in future validation studies. Furthermore, 9 participants disagreed/strongly disagreed with the statement, “Estimating the number of servings of a standard portion size was easy”. Thereby, future studies will require respondents to receive food portion size booklets or a standard weighing scale for estimating the portion of foods consumed. Three respondents also suggested in improving the app by adding a timely notification feature to record food items. The response to the statement "The foods I usually consume were easy to find on the app" was neutral by 13 participants. Therefore, food database must be continually expanded to include a greater variety of foods representing various nationalities.

4.5 Conclusion

The objective of the current preliminary study was to validate and evaluate the performance of self-administered smartphone application ‘Diet DQ Tracker’ against interviewer-administered 24-h telephone recall. The findings of this study demonstrated a high degree of agreement between the two methodologies by establishing nearly identical mean DDS’s at group level. In general, respondents found the app easy to use, convenient, enjoyable and were highly satisfied with the performance. As a result, all respondents preferred the ‘Diet DQ Tracker’ over traditional methodology in the present study. ‘Diet DQ Tracker’ is a functional tool facilitating dietary data collection for research by reducing the perceived workload, effort, time and resource utilization. The app provides real-time dietary feedback, prompting respondents to consume diverse and healthy diets. However, the performance of ‘Diet DQ Tracker’ should be compared to conventional methodology in large-scale studies involving respondents of various population groups. Further research is warranted to investigate different sources of variations between both methodologies.

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Summary

Traditional methods of collecting dietary data, particularly interviewer-administered 24-h dietary recall, have innate limitations, such as recall bias, social desirability bias, respondent burden, interviewer burden, and cost-time constraints, all of which impair data collection and thus negate the objectivity of assessment measures. In the area of dietary assessment, technological innovations appear to be promising for identifying and mitigating measurement errors. With the global proliferation of smartphones, the replacement of traditional dietary data collection methodologies with smartphone applications that move inline with modernity and technology has become irrefutable.

The primary objective of this study was to design and develop the very first self-administered smartphone application 'Diet DQ Tracker', capable of collecting dietary data for the diet diversity indicators MDD-W, IYCF-MDD, and HDDS, by replacing traditional methodology of interviewer-administered 24-h dietary recall. The application incorporates a novel and comprehensive food composition database containing 8777 food items, enabling it to compute real-time diet diversity scores based on respondent's dietary intake, and recommends food consumption based on the SAIN, LIM nutrient profiling system. The application analyzes and visualizes the diet diversity score gleaned from all meal entries recorded by a respondent throughout the day, followed by permanent cloud storage, accessible via desktop-based CMS application. The CMS application allows the research team to add, delete, or edit food items and their nutritional content in the food database in response to the respondent demand and recent updates to food composition tables.

The secondary objective of this study was to compare the acceptability, feasibility, and relative validity of the 'Diet DQ Tracker' with reference to the traditional methodology of 24-h interviewer-administered dietary recall. The 'Diet DQ Tracker' was used to collect dietary data for MDD-W and HDDS from 20 respondents over three consecutive days. To collect data from both methodologies on an overlapping day, the 24-h telephone recall was administered the next day, capturing data for the same day the app was used. Following dietary data collection, respondents completed a user feedback survey regarding their experience with both methodologies. Diet diversity scores acquired using both methodologies revealed no significant differences at the group level, indicating a satisfactory level of agreement. Respondents generally found the app simple to use, convenient, enjoyable, and expressed high satisfaction with its performance. As a result, all respondents preferred ‘Diet DQ Tracker’ over the traditional methodology.

5.2 Future recommendations

1) The ‘Diet DQ Tracker’ validation study should be evaluated with multiple 24-h dietary recalls in large scale studies involving respondents from various age groups with diverse socio-demographic and educational backgrounds.
2) Moreover, biological methods such as DLW can also be used as reference methodology for evaluating the performance of ‘Diet DQ Tracker’.
3) The ‘My meals’ section on the ‘Progress’ page of the application should be inaccessible to respondents in subsequent versions of the ‘Diet DQ Tracker’ designed specifically for the validation study.
4) For future studies, food portion size booklets or a standard weighing scale can be used to estimate the portion of foods consumed.
5) Subsequent versions of the application may also include a timely notification feature reminding respondents to record their dietary intake on the app.
6) The food database must be continually expanded to include a greater variety of foods representing various nationalities and to keep the food composition table up to date.
7) The application can be enhanced with a new food recognition feature that enables users to record the name of a food item and estimate the portion size, simply by taking a picture of it.
8) In the subsequent large-scale validation studies of ‘Diet DQ Tracker’, future versions of the application can also be refined based on user comments and suggestions gathered through the user feedback survey.

APPENDIX

A1. User feedback on dietary assessments

Number of respondents		20 (10 Female; 10 Male)		
1.	**General statements** *To begin with the survey, I'd like to read a few statements regarding the dietary survey in which you agreed to participate. I will read the statements for you; please choose one of the options below. Please select, whether you strongly agree, agree, are neutral, disagree, or strongly disagree with the following statements.*	**Agree / Strongly agree**	**Neutral**	**Disagree / Strongly disagree**
1.1	The Diet DQ app is easy to understand.	**19**	**1**	
1.2	The Diet DQ app is easy to use.	**19**	**1**	
1.3	The foods I usually consume were easy to find on the app.	**5**	**13**	**2**
1.4	Foods and beverages were recorded on the app right after consumption.	**11**	**9**	
1.5	Recording food items right after consumption affected my daily routine.	**1**	**7**	**12**
1.6	During the interview administered recall session, remembering the food items consumed the previous day was difficult.	**5**	**6**	**9**
1.7	Meals logged the day before were checked prior to or during the interviewer-administered recall session.	**13**	**4**	**3**
1.8	Recording food items in the ‘Search as you type’ textbox was convenient.	**10**	**6**	**4**
1.9	Estimating the number of servings of a standard portion size was easy.	**6**	**5**	**9**
1.10	Custom recipes were frequently recorded on the Diet DQ app.	**8**	**7**	**5**
1.11	Recording custom recipes on the app was difficult.	**4**	**12**	**4**
1.12	The ‘repeat previous food’ feature was often used.	**2**	**7**	**11**
1.13	Graphic visualizations of the diet diversity scores were frequently accessed.	**19**	**1**	
1.14	The graphic visualizations prompted the consumption of diverse food groups for the purpose of achieving a higher score.	**15**	**5**	
1.15	SAIN, LIM recommendations for foods consumed were frequently checked.	**15**	**4**	**1**
1.16	SAIN, LIM recommendations prompted the consumption of healthy foods.	**16**	**4**	
1.17	Overall, the Diet DQ app proved to be highly satisfactory.	**18**	**2**	

2.	**The preferred methodology**		
2.1	Which is your preferred methodology for dietary assessment?	App	Interview Administered Recall
		20	

	Provide Yes or No answers below. Was your preferred dietary assessment methodology:	Yes/No
2.2	More convenient?	Yes (20)
2.3	Easy to use?	Yes (20)
2.4	Less time consuming?	Yes (20)
2.5	Easy to remember?	-
2.6	Portable?	Yes (20)
2.7	Enjoyable to use?	Yes (20)
3.	**Duration questions**	**Time (min.)**
3.1	Approximately how long did it take to record an entire day's food intake on the Diet DQ app?	8.4
3.2	Approximately how long did it take to recall and inform the interviewer about the previous day's food consumption?	10.25

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Chapter III

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