Towards improved designs of nutrition-sensitive agriculture projects that follow multi-pathway approaches

By

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ABSTRACT

Despite the agricultural efforts to produce calorically dense staple crops, a significant part of the global population still suffers from malnutrition. This thesis aimed to explore different forms of malnutrition: deficiencies of micronutrients (i.e., vitamins and minerals) and macronutrient malnutrition (i.e., proteins deficiency, and overnutrition as overweight and obesity); how agriculture has been transformed into a highly complex scheme aiming at improving the nutritional status in a sustainable way: the nutrition-sensitive agriculture (NSA) approach; and how to develop a tool that systematizes the decision-making process in NSA projects and overcomes the difficulties in the tasks of designing them.

We found that current NSA projects have been designed mostly within the food production aspect, such as diversification of agricultural production or nutrition-sensitive livestock. To assess the impact of NSA projects, individual- and household-level dietary indicators (e.g., Minimum Dietary Diversity for women of reproductive age (MDD-W) and for young children (MDD-C), household dietary diversity score (HDDS)), have been common selections, as well as nutritional status indicators (e.g., iron status, stunting, wasting). In some studies, indicators have been inappropriately used, for instance, HDDS as a measure of diet quality, when it determines food access. This can be attributed to the difficulty in keeping track of what numerous indicators do and do not reflect. Well-designed, targeted, and implanted NSA projects are successful when they integrate components from different sectors, such as agriculture, women's empowerment, water, sanitation and hygiene, rather than nutrition issues alone, hence the complexity in their design. The multi-criteria decision analysis (MCDA) methods have helped solve agriculture-related problems, but, to our knowledge, they have not been used for the complex tasks of designing NSA projects.

We integrated the Entropy-based Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), an MCDA method, into the development of an algorithm that helps select the most suitable types of interventions, metrics and indicators, given the context of a project. This tool, anticipated to be designed as a smartphone application, was validated using published NSA studies, comparing what types of interventions the authors chose to implement versus the ones that the algorithm suggested, obtaining Kendall's correlation coefficients (τ) from $\tau = 0.9263$ to $\tau = 0.9895$. We also compared the indicators that the authors used to measure outcomes and impacts versus the ones that the algorithm awarded with more points. Our algorithm addresses the gap related to the convolution of NSA projects that follow multi-pathway approaches, by making it easier to keep track of what each metric and indicator reflect to avoid making erroneous selections. The blueprints of the smartphone application were presented, among its main features.

By using our algorithm, we concluded that a Nutrition education intervention was the most suitable (closeness value of cv = 0.6157) for Jesús de Menchaca, a Bolivian community. Therefore, a behavior change communication program was designed, considering the traditional dishes that people already consume in that community. Three of the indicators that our algorithm suggested (MDD-W, MDD-C, HDDS) can be assessed with 'DQ Tracker', a convenient smartphone application developed by our team that has been validated against the 24-h recall, the conventional and time-consuming methodology.

The results of this study are expected to enhance the design of NSA interventions by avoiding the wrong use of metrics and indicators, and it is also expected to make the task less overwhelming for managers, designers, and stakeholders.

RÉSUMÉ

Malgré les efforts agricoles visant à produire des cultures de base à forte densité calorique, une partie importante de la population mondiale souffre toujours de malnutrition. Cette thèse vise à explorer : des différentes formes de malnutrition comme les carences en micronutriments (vitamines et minéraux) et la malnutrition en macronutriments (carence en protéines ou surnutrition menant au surpoids et à l'obésité) ; comment l'agriculture a été transformée en un programme visant à améliorer l'état nutritionnel de manière durable que l'on identifie comme l'approche de l'agriculture sensible à la nutrition (NSA) ; et comment développer un outil qui systématise le processus de prise de décision dans les projets NSA et comment surmonter les difficultés liées la conception de ces projets.

Présentement, les projets NSA sont principalement orientés vers le domaine de la production alimentaire, comme la diversification de la production agricole ou l'élevage sensible à la nutrition. L'évaluation de l'impact de ces projets NSA est généralement fait à partir d'indicateurs alimentaires aux niveaux individuel et familial (e.g. diversité alimentaire minimale pour les femmes en âge de procréer (MDD-W), pour les jeunes enfants (MDD-C), ou encore, en utilisant le score de diversité alimentaire des ménages (HDDS)), et des indicateurs de l'état nutritionnel (e.g. statut en fer, retard de croissance, émaciation). Dans certaines études, des indicateurs ont été utilisés de manière inappropriée car ceux-ci sont souvent mal définis. Pour réussir, les projets NSA bien conçus doivent intégrer des composantes de différents secteurs, tels que l'agriculture, l'autonomisation des femmes, l'eau, l'assainissement et l'hygiène. Les méthodes d'analyse décisionnelle multicritère (MCDA) ont permis de résoudre des problèmes liés à l'agriculture, mais, à notre connaissance, elles n'ont pas encore été utilisées pour la conception de projets NSA.

Nous avons utilisé une méthode MCDA basée sur l'entropie pour la préférence de commande par similarité avec une solution idéale (TOPSIS) pour développer un algorithme qui aide à sélectionner les types d'interventions, les métriques et les indicateurs qui tiennent comptes du contexte d'un projet NSA. Cet outil, conçu pour être utilisé sur un smartphone, a été validé à l'aide de résultats publiés de projets NSA. Ceci nous a permis de comparer les types d'interventions que les auteurs avaient choisi à celles suggérées par l'algorithme et nous avons obtenu des coefficients de corrélation de Kendall (τ) de $\tau = 0{,}9263$ à $\tau. = 0{,}9895$. Nous avons également comparé les indicateurs utilisés par les auteurs pour mesurer les résultats avec ceux choisi par l'algorithme. Notre algorithme a permis de combler l'écart lié à la convolution des projets de la NSA qui suivent des approches multivoies, ce qui a facilité le suivi précis de ce que reflètent chaque métrique et indicateur choisis et d'éviter de faire des sélections erronées. Une version préliminaire de l'application pour smartphone a été présentée et testés.

L'utilisation de l'algorithme, nous a proposé qu'une intervention d'éducation nutritionnelle était la plus appropriée (valeur de proximité de cv = 0,6157) pour régler les problèmes de mal nutrition de la communauté bolivienne de Jesús de Menchaca. Par conséquent, un programme de communication a été mis en place pour modifier le comportement alimentaire en tenant compte des plats traditionnels. Les trois indicateurs de performance suggérés par l'algorithme étaient le MDD-W, le MDD-C, et le HDDS. Ces trois indicateurs peuvent être pris en charge par l'application « DQ Tracker », une application pour smartphone développée par notre équipe. Cette dernière a été validée par rapport au rappel de 24 heures, au rappel conventionnel et à la méthodologie chronophage.

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CONTRIBUTION OF AUTHORS

The role and contribution made by different authors are as follows: Arturo Mayorga-Martínez is the principal author of this work. He is the Ph.D candidate who designed and executed all parts of this research, data analysis, manuscript writing and revision for scientific publications. Professor Michael Ngadi is the thesis supervisor, who guided the candidate in the stages of planning, design, and execution of the research, and analysis of the data during the entire program. He also corrected, edited, and reviewed all the manuscripts sent for publications.

Dr. Ebenezer Kwofie contributed in conceptualizing the overall project, giving guidance in outlining and shaping the framework of the research, and revising the manuscripts. Dr. Christopher Kucha contributed in revising the manuscripts as well, giving valuable feedback to improve the study and the revision of the manuscripts.

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NOMENCLATURE

24HR	24-hour recall
AA	Amino acids
AHP	Analytic hierarchy process
AIUDA	Analysis of interconnected decision analysis
BCC	Behavior change communication
BMI	Body mass index
CSI	Coping strategies index
CV	Closeness value
ELCSA	Latin American and Caribbean food security scale
ELECTRE	Elimination and choice expressing the reality
FAO	Food and agriculture organization
FCS	Food composition score
FFQ	Food frequency questionnaire
FIES	Food insecurity experience scale
FR	Food record
GUI	Graphical user's interface
HDDS	Household dietary diversity score
HFIAS	Household food insecurity access scale
HHI	Hidden hunger index
HHS	Household hunger scale
ID	Iron deficiency

IDA	Iron deficiency anaemia
IDDS	Individual dietary diversity score
IFAD	International fund for agricultural development
IYCF	Infant and young child feeding
MAD	Minimum acceptable diet
MAHFP	Months of adequate household food provisioning
MAUT	Multi-attribute utility theory
MAVT	Multi-attribute value theory
MCDA	Multi-criteria decision analysis
MDD-C	Minimum dietary diversity for infants and young children
MDD-W	Minimum dietary diversity for women of reproductive age
MMF	Minimum meal frequency
MUAC	Mid upper arm circumference
NSA	Nutrition-sensitive agriculture
PEM	Protein energy malnutrition
PLA	Participatory learning and action
PROMETHEE	Preference ranking organization method for enrichment evaluations
RAE	Retinol activity equivalents
RCT	Randomized control trial
RDAs	Recommended dietary allowances
SCR	Screener
SDGs	Sustainable development goals
SODA	Strategic options development and analysis

SWOT	Strengths, weaknesses, opportunities, threats
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UNICEF	The United Nations International Children's Emergency Fund
VAD	Vitamin A deficiency
VIKOR	Multi-criteria optimization and compromise solution
WASH	Water, sanitation, and hygiene
WEAI	Women empowerment in agriculture index
WFP	World food programme
WHO	World health organization

I. GENERAL INTRODUCTION

1.1 Background

Despite the efforts to tackle global food insecurity, there is still much left to do to combat malnutrition in vulnerable communities. Undernutrition —insufficient intake of energy and/or nutrients— affects almost 40% of the global population: 2 billion people suffer from micronutrient deficiencies (a.k.a., hidden hunger) and almost 800 million people deal with energy deficiency (IFPRI, 2016; Maleta, 2006). Low and middle-income settings have been associated with undernutrition due to the fact that staples with low availability of vitamins, minerals and other essential nutrients (e.g., amino acids) are predominant foods in low and middle-income countries (Green et al., 2016; Kennedy et al., 2007).

Since 80% of rural populations work in the agricultural sector (Ruel and Alderman, 2013), agriculture is regarded as a key tool to fight against malnutrition. In the past, however, agriculture policies focused heavily on food security, relying on improving yields of staple crops, such as wheat, maize and rice; on the other hand, the production of fruit, vegetable, pulse and nut crops was neglected (DeFries et al., 2015). Therefore, the populations were consuming caloric diets lacking important micronutrients. Fortunately, nutrition-sensitive agriculture (NSA) has been developed over the last decade.

NSA is an approach that seeks to ensure, in a sustainable manner, the production of a variety of affordable, nutritious, culturally appropriate, and safe foods in sufficient quantity and quality to meet the dietary requirements of a population (FAO, 2017). The ultimate goal of NSA projects is to improve the nutritional status of vulnerable communities by addressing the underlying causes of nutrition (e.g., access to safe and nutritious food, nutrition knowledge and norms, income, women empowerment) (Herforth and Ballard, 2016). FAO (2017) shows the principles that should be considered when designing an NSA intervention. Besides assessing the context of the target community, they recommend collaborating with different sectors and programs (e.g., government, health, nutrition) and incorporating nutrition objectives and indicators in the design, as well as nutrition promotion and education. They also provide a list of possible NSA interventions, classified according to the main functions of the food system or cross-cutting issues.

Appropriate indicators are necessary to measure the impact (positive or negative) of an NSA intervention. The selection of the indicators depends on the pathway(s) that the intervention(s) follow(s). FAO (2016) offers a compendium of over 60 indicators, classified into 10 categories: diet quality; food access; on farm availability, diversity and safety of food; food environment in markets; income; women's empowerment; nutrition and food safety knowledge and norms; care practices; natural resource management practices, health and sanitation environment; and nutritional status (anthropometric and biochemical measures).

To assess an indicator, certain data should be collected with different metrics. For example, if the purpose is to determine diet quality, there are different dietary assessment instruments that could be used: 24-h dietary recall (24H), food record (FR) (a.k.a. food diary), food frequency questionnaire (FFQ) and screeners (SCR). Each metric measures different aspects of the diet quality. For instance, 24H obtains detailed information about all foods and beverages consumed on a given day, whereas the FFQ obtains frequency and, in some cases, portion size information about food and beverage consumption over a specific period, typically the past month or year. Utility and limitations of data obtained by each instrument, as well as a comprehensive comparison among them are available (NIH, n.d.). For instance, the FR is appropriate only for cross-sectional and prospective studies, while 24H, FFQ and SCR are good for interventions.

There are still some gaps when it comes to designing NSA interventions. For example, each project needs to be analyzed ex ante for a clear theory of change. In some cases, it is not very clear what interventions are the most suitable for a certain community. Furthermore, the most appropriate indicators will vary, depending on the nature of the intervention and the pathway that it follows. Since there are too many metrics and indicators, it can be difficult to keep track of what each one reflects, and this leads to a risk of misinterpreting them and/or choosing some that are not the most adequate. Verger et al. (2019) found that, at the household level, half of the studies that they reviewed were not consistent in terms of use and interpretation of simple food group dietary diversity indicators; the interpretation, for instance, was misleading in some cases (e.g., interpreted results of household dietary diversity score (HDDS) as a measure of diet quality, household nutrition or nutritional status, when it really is a measure of food access).

Increasing on-farm production diversity is an example of an NSA project as it aims to improve smallholders' diet diversity and nutrition. Sibhatu and Qaim (2018) analyzed 45 studies and found that, even when farm production diversity had a statistically significant impact on household-level dietary diversity and nutrition in some situations, the effect was usually small in magnitude. Besides, some studies showed positive associations when using certain indicators of diet and nutrition but not when using others. Ruel et al. (2018) also reviewed NSA studies in which crop production diversity was positively associated with dietary diversity and child nutrition outcomes in certain contexts; they noticed that the dietary diversity relationship may even turn negative where farm production diversity was already high, owing to the forgone income resulting from farm diversification beyond optimal levels. Bird et al. (2019) reviewed studies performed in South Asia and concluded that there was no strong evidence linking the agricultural interventions to final measures of nutritional status (e.g., anthropometric measures); they found, however, a potential of these interventions to improve intermediate outcomes (e.g., dietary diversity). These mixed results can be attributed to methodological limitations, such as sample sizes and time frame (e.g., anthropometric indicators are selected when interventions are not lasting enough to perceive significant improvements in stunting or wasting); contextual and seasonal constraints, lack of comparability of the agricultural interventions, non-homogeneity of units of observation (e.g., households, women, children); and variability of metrics (Estrada-Carmona et al., 2020). Therefore, there is a strong need of optimizing the design of NSA interventions to continue conducting research in this critical area to meet the globally agreed sustainable development goals. Multi-criteria decision analysis (MCDA), which involves the analysis of several available options in social sciences, engineering, medicine, and many other research areas, through computational methods, represents a powerful tool that might help with this purpose.

1.2 Hypothesis

The hypothesis in this study claims that MCDA methodology could provide guidance in the design of NSA projects, based on the context of a target community; a ranking method (i.e., TOPSIS) could help select the most appropriate type(s) of NSA interventions; the selection of the right intervention(s) could help choose what pathway(s) to follow; once the pathways are defined, the most appropriate metrics and indicators might be determined; a smartphone application that integrates the whole process not only to design the NSA project but also to gather information to assess the baseline data and to evaluate the impact (positive or negative) could be mocked up.

1.3 General objective

The general objective of this study is to develop an algorithm to guide the user in making decisions when choosing the types of nutrition-sensitive agriculture interventions in the process of planning an NSA project. By making sure that the most suitable indicators are selected, the ensuing tool is anticipated to avoid misinterpretations on the measurement of diet quality, care practices, health environment, and the rest of the steps of the pathway towards the nutritional status of the communities where the intervention(s) take(s) place. The tool will be helpful for project managers, designers, and stakeholders.

1.4 Specific objectives

To contribute to the overall objective, the specific goals for this project are:

1. To analyze the full pathway(s) that the different types of NSA interventions may follow towards improving the nutritional status of vulnerable communities.
2. To determine the current tools that are used for the measurement of the full pathway of change from agricultural inputs and practices to nutrition outcomes.
3. To perform a meta-analysis of current NSA projects to understand their core characteristics (e.g., target population, sample size, pathways, metrics, indicators), and to validate the adopted methodologies.
4. To explore the feasibility of Multi-Criteria Decision Analysis (MCDA) in developing the technological tool to design and to evaluate the NSA intervention(s).
    a) To use the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), to determine, based on the context of the community and the priorities of the project managers or designers, the NSA interventions that are the most suitable for the target community.
    b) To create a selection criterion to fit a chosen algorithm for the most appropriate

pathways, metrics and indicators, and to associate them with the questions required to gather data.

5. To create the blueprints of the smartphone application that should help design NSA interventions with the TOPSIS method, enlisting the main features.
6. Based on the MCDA results, to design an NSA intervention for the community Jesús de Machaca, in Bolivia, so that further implementation can be executed.

II. GENERAL LITERATURE REVIEW

2.1 Different forms of malnutrition

Malnutrition has been identified as the primary cause of immunodeficiency worldwide, being infants, children, adolescents, and the elderly the most vulnerable ones to infections (Katona and Katona-Apte, 2008). Malnutrition gets even worse in low- and middle-income settings, where populations in all levels (i.e., countries, communities, families, and individuals) deal with the double burden of malnutrition, which consists of childhood growth failure due to micronutrient deficiencies, and overnutrition in the form of overweight or obesity (Popkin et al., 2020). Many countries suffer from simultaneous forms of malnutrition, such as child undernutrition, anaemia among women, and adult obesity (FAO et al., 2017).

2.1.1 Micronutrient deficiencies

There are different types of micronutrient deficiencies (a.k.a. hidden hunger). While iron, iodine, and vitamin A deficiencies have long been endemic on a global scale (Figure 2.1), zinc, vitamin D, vitamin B12 and riboflavin (B2) are also of concern (Magee and McCann, 2019). The average recommended amounts of these micronutrients depend on sex, age or pregnancy status. Figure 2.1 shows the distribution of hidden hunger in the world, based on the hidden hunger index (HHI-DP). Sub-Saharan Africa is a region where the HHI-DP is alarmingly high, and countries from South-Central/South-East Asia show severe hidden hunger. Most South American countries, on the other hand, show from mild to moderate HHI-DP (Muthayya et al., 2013). It has been shown that even mild to moderate micronutrient deficiencies can impede physical and cognitive development, stunt physical growth, raise infection morbidity in infants and young children, and lower work productivity in adults (Muthayya et al., 2013).

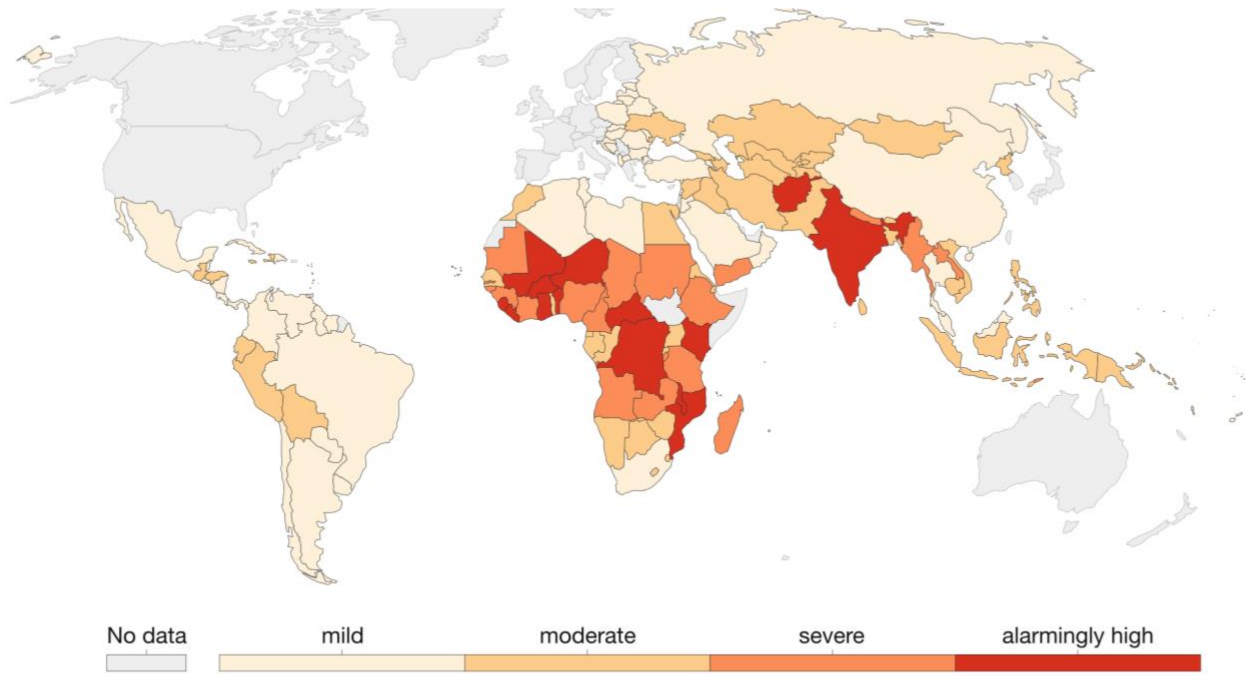

Figure 2.1 Global map displaying hidden hunger index (HHI-PD) based on the prevalence estimates (i.e., prevalence of stunting, anemia due to iron deficiency, and low serum retinol concentration) in 149 countries. As suggested by Muthayya et al. (2013), HHI-PD scores between 0.0 and 19.9 were considered mild, 20.0-34.9 as moderate, 35.0-44.9 as severe, and 45.0-100 as alarmingly high.

2.1.1.1 Iron

Iron deficiency (ID) can cause iron deficiency anaemia (IDA). IDA represents a disease burden worldwide that affects about 1.2 billion people, based on data from 2016, representing the leading cause of years lived with disability in low- and middle-income countries (Camaschella and Girelli, 2020; Pasricha et al., 2021; Vos et al., 2017). Iron is an integral part of haemoglobin, a protein found in blood; due to increased iron needs (e.g., body growth, growth of maternal and foetal erythroid mass), pregnant and premenopausal women and children under 5 years of age are among the most vulnerable ones to develop IDA (Camaschella and Girelli, 2020; Pasricha et al., 2021; Shubham et al., 2020; Vos et al., 2017). Apart from nutritional deficit, IDA is also associated with a sedentary lifestyle that often leads to obesity and diabetes (Shubham et al., 2020).

Loss in weight and frequent respiratory and intestinal infections are among the consequences of IDA in children, as well as impaired in behaviour and psychomotor skills (e.g., decrease in ability to concentrate has been observed in children and adolescents) (Camaschella and Girelli, 2020; Shubham et al., 2020). In the case of adults, IDA can cause reduction in physical capacity. Frail nails, koilonychia, hair loss, cheilitis, atrophic glossitis, dysphagia (due to Plummer-Vinson pharyngo-oesophageal webs) have been identified as signs of epithelial ID (Camaschella and Girelli, 2020).

Iron can be obtained from a wide variety of foods: lean meat, seafood, poultry, iron-fortified breakfast cereals and breads, white beans, lentils, spinach, kidney beans, and peas, nuts and some dried fruits such as raisins; iron from plants is absorbed better when it is consumed with meat, seafood, poultry or foods rich in vitamin C and citric acid, such as citrus, strawberries, sweet peppers, tomatoes, and broccoli (NIH, n.d.). On the other hand, minerals like Ca, P, Mg, and other chemical compounds such as malonaldehyde, oxalic and phytates have been recognized as anti-nutritional, inhibitors of iron absorption (Martínez-Navarrete et al., 2002). The recommended dietary allowances (RDAs) for iron for males and females range from 7-11 mg, being higher during the 7-12 months of age and 4-8 years of age; during adulthood (19-50 years of age), the RDAs are 11 mg for men, 18 mg for non-pregnant women, 27 mg for pregnant women, and 10 mg for lactating women (Institute of Medicine, 2001).

2.1.1.2 Iodine

Iodine is essential for the production of thyroid hormones; thus adequate intake of this trace mineral will prevent thyroid dysfunction to maintain normal physiological functions of the body (Zimmermann, 2011). Based on the latest scorecard by the Iodine Global Network, 115 countries are classified as having optimal iodine nutrition, while 23 countries are still classified as iodine deficient (Olivieri et al., 2020). Iodine intake is classified as excessive in 14 countries, three of which are from Latin America: Honduras, Costa Rica and Colombia, while Dominican Republic and Nicaragua suffer from an insufficient iodine intake (Iodine Global Network, 2020; Zimmermann, 2011). Globally, about 2 billion people are at risk of iodine deficiency (de Benoist et al., 2008).

Dietary iodine is swiftly and almost completely absorbed (> 90%) (Alexander et al., 1967; Nath et al., 1992). Thyroid and kidney clear iodine from circulation, being constant the renal clearance, while thyroid clearance depends on the iodine intake (Zimmermann, 2011). It has been reported that the body of a healthy adult contains up to 20 mg of iodine, of which 70-80% is in the thyroid (FISHER and ODDIE, 1969). In children and adolescents, a deficiency of iodine can lead to mental and growth retardation, whereas in adults, iodine deficiency has been associated with an impaired mental function, reduced work output, goitre and hypothyroidism (Krela-Kaźmierczak et al., 2021).

Iodine can be found in a wide range of foods: fish, seafood, milk, dairy, vegetables and fruits (Krela-Kaźmierczak et al., 2021). The concentration in which iodine can be found, however, depends on several factors, such as the type of soil and world region in which agricultural crops were planted (NIH, n.d.), whether the plant is marine or terrestrial (Fuge and Johnson, 1986), the season in which milk is obtained or whether the milk is organic or conventional (Krela-

Kaźmierczak et al., 2021; O'Kane et al., 2018). Besides, although salt consumption has been limited due to health issues related to sodium intake, iodized salt is still the primary source of iodine (Krela-Kaźmierczak et al., 2021). The average daily recommended amounts of iodine depend on age: 110 µg for newborns, 130 µg for infants (7 to 12 months), 90 µg for children (1-8 years), and 150 µg for teenagers and adults (NIH, n.d.). There are several reasons why, during pregnancy, the iodine requirement is increased ≥ 50% (220 µg for pregnant teens and women, and 290 µg for lactating teens and women): (1) an increase in maternal thyroid hormone production to maintain maternal euthyroidism and transfer thyroid hormone to the foetus early in the first trimester, before the foetal thyroid is functioning; (2) iodine transfer to the foetus, particularly in later gestation; and (3) an increase in renal iodine clearance (Glinoer, 1997).

2.1.1.3 Zinc

It had been considered that zinc was not a world health problem, but now it is regarded as an acute problem because an estimated of 17.3% of the global population is at risk of inadequate zinc intake, making zinc deficiency the most widespread micronutrient deficiency among all the micronutrients and different crops: the fifth most important health risk factor in developing countries and eleventh worldwide (Naik and Das, 2008; Sharma et al., 2013; Wessells and Brown, 2012). Zinc deficiency takes place not only because of a low intake of zinc, but also because of other factors, such as interference of other dietary factors with the absorption and bioavailability of dietary zinc (e.g., phytate, which binds in the intestinal lumen and accounts for the lower efficiency of absorption from plant foods), enlarged losses of zinc, reduced utilization, and increased requirements for zinc during physiological conditions (e.g., periods of rapid growth, pregnancy and lactation) (Roohani et al., 2013).

The zinc concentration in blood does not abate in proportion to the degree of deficiency, which causes physical growth to slow down, and excretion to be reduced in order to conserve zinc; therefore, most children suffering from this deficiency have stunted linear growth (Graham, 2008). Zinc deficiency in humans also reduces serum testosterone levels, which is associated with an immune disfunction called oligospermia, affecting T helper cells, hyperammonaemia, neurosensory disorders and decrease in lean body mass (Prasad, 2008).

The sources of zinc include oysters, red meats, liver, nuts, and seeds, being the animal source (from 0.40 to 6.77 mg per 100 g) richer than the plant source (cereal grains have 0.30 to 2.54 mg per 100 g, vegetables from 0.12 to 0.60 mg per 100 g and fruits from 0.02 to 0.26 mg per 100 g) (Haase and Rink, 2014; Haeflein and Rasmussen, 1977). Crops that are produced in flooded conditions might present an increase in phosphorus and bicarbonate concentration, which affects negatively the soil zinc availability to the crop (Sharma et al., 2013). Besides, zinc in animal products is more easily absorbed than that of plant foods (Knez and Stangoulis, 2021). As with other micronutrients, the RDAs for zinc vary depending on age, sex and stage of life. For both male and female children, it is the same during the first stages: 3 mg (7 months to 3 years of age), 5 mg (4-8 years of age), 8 mg (9-13 years of age); 11 mg for adult males, 8-9 mg for adult non-pregnant teens and women, 11-12 mg for pregnant teens and women, and 12-13 mg for lactating teens and women.

2.1.1.4 Vitamin A

Vitamin A (all-trans retinol), together with its natural derivatives and synthetic analogues, constitutes the group of retinoids (McLaren and Kraemer, 2012). By two successive oxidative reactions, retinoids are transformed into their biologically active form: retinaldehyde and retinoic acid (Timoneda et al., 2018). It cannot be synthetized by vertebrates; it must be obtained from the diet. Vitamin A deficiency (VAD) is a global health concern because about 30% of children under 5 years of age in the world are vitamin A deficient and 2% of all deaths are attributed to VAD in this age group (Stevens et al., 2015). VAD is associated with increased risk of health problems in children, such as diarrhoea, measles, vision problems (VAD is among the leading causes of preventable childhood blindness, which affects around 250 million preschool children), impaired immune functions and anaemia (Gogate et al., 2009; Schultink, 2002; World Health Organization, 2020).

Vitamin A can be present in foods as retinyl esters, and all-trans-retinol, which come from animal sources, such as milk, eggs, liver, and food products that have been fortified with vitamin A or provitamin A, other carotenoids, mainly β-carotene, which are partly converted to vitamin A in the intestinal mucosa, and other peripheral non-digestive tissues (e.g., adipocytes, macrophages) (Lobo et al., 2010; Relevy et al., 2015). Most provitamin A comes from leafy green vegetables (e.g., spinach, broccoli), orange and yellow vegetables (e.g., carrots, squash), tomato products, fruits (e.g., yellow ripe mangos), and some vegetable oils (NIH, n.d.; Timoneda et al., 2018). The requirements of vitamin A are based on the adequate concentration that should be maintained in the liver (20 µg vitamin A/g liver), and are expressed in retinol activity equivalents (RAE) (Timoneda et al., 2018). One µg of RAE is the biological activity associated with 1 µg of all-*trans*-retinol and it is equivalent to 12 µg of β-carotene and to 24 µg of α-carotene or β-cryptoxanthina (other carotenoids found in food, such as lycopene, lutein and zeaxanthin are not metabolic precursors for vitamin A) (NIH, n.d.; Timoneda et al., 2018). The RDAs for vitamin A range from 300 to 600 µg RAE for children and teenagers; it is 900 µg RAE for male adults, 700 µg RAE for non-pregnant female adults; 750-770 µg RAE for pregnant teens and women and 1200-1300 µg for lactating teens and women (NIH, n.d.). A diet in which vitamin A comes mostly from fruits and vegetables, will probably lead to VAD, therefore, developing countries are susceptible to this deficiency.

2.1.1.5 Vitamin B complex

The vitamin B complex include 8 vitamins. However, the deficiency of only two of them will be covered: riboflavin (a.k.a. vitamin B2), and cobalamin (a.k.a. vitamin B12). As opposed to other micronutrient deficiencies, vitamin B complex deficiency is rare because these vitamins are present in a wide variety of foods. Nevertheless, individuals who opt for vegan diets or diets scarce in milk and meat can develop deficiency of these vitamins.

Vitamin B2 deficiency was detected in a significant number of subjects (25-75th percentile was at the level of 30-50%) and was encountered in the Russian Federation in a studied period from 1987-2017 (Kodentsova et al., 2018). Vitamin B2 is not only mostly present in animal products, but also its absorption from foods from plant origin is lower, as shown in some cross-sectional studies (Allès et al., 2017; Elorinne et al., 2016; Kristensen et al., 2015). Vitamin B2 deficiency has been diagnosed in one quarter of vegans and 14% of omnivores in a Swiss population (Schüpbach et al., 2017).

Riboflavin is an essential component of two major coenzymes: flavin mononucleotide and flavin adenine dinucleotide, which play roles in energy production, cellular function, growth and development, and metabolism of fats, drugs and steroids (NIH, n.d.). The signs and symptoms of vitamin B2 deficiency, also known as ariboflavinosis, include skin disorders, hyperaemia and oedema of the mouth and throat, angular stomatitis, cheilosis, hair loss, reproductive problems, and degeneration of the liver and nervous system; anaemia can also be developed when ariboflavinosis is severe and prolonged.

Foods rich in vitamin B2 include eggs, kidneys, liver, lean meats, and milk; green vegetables also contain riboflavin but as mentioned above, its absorption is less than that of animal products; and grains and cereals are fortified with vitamin B2 in many countries (McCormick, 2012; Medicine, 1998; Ross et al., 2012). The RDAs, for both male and female from birth to 13 years of age, ranges from 0.3 mg to 0.9 mg. For adults, the RAE is slightly higher for male (1.3 mg) than for non-pregnant teens and women (1.0-1.1 mg). However, the RAE is 1.4 mg for pregnant teens and women, and 1.6 mg for lactating women.

As it happens with riboflavin, vitamin B12 deficiency occurs in individuals that do not consume products from animal origin, vegans and also people who belong to low socioeconomic status (Chittaranjan, 2020). High prevalence of vitamin B12 deficiency has been confirmed among men in Pune, being twice as common in the urban middle-class men compared with those from rural communities, which was attributed to the higher prevalence of vegetarianism, better education and hygiene, and higher obesity in the middle class (Chittaranjan, 2020, p. 12; Yajnik et al., 2006).

Cobalamin is essential for the development of the nervous system in infancy and early childhood, as well as for healthy red blood cell formation, and DNA synthesis (Allen, 2012; Medicine, 1998; Stabler, 2012). The autoimmune disease pernicious anaemia is the most common cause of severe malabsorption of vitamin B12, and this disease can manifest in people from all ethnic groups and races of the world, and the prevalence increases with age and female sex (Stabler, 2012). Other effects of vitamin B12 deficiency include low counts of white and red blood cells, and neurological changes, such as numbness and tingling in the hands and feet, which can occur with or without anaemia (NIH, n.d.; Stabler, 2012).

As a vitamin that belongs to the vitamin B complex, cobalamin is found naturally in foods of animal origin, such as dairy products, meat, eggs, fish, and shellfish (Allen, 2012). The RDAs range from 0.4 µg to 1.8 µg for both male and female infants and children (up to 13 years of age); they increase to 2.4 µg for male and non-pregnant teens and women, 2.6 µg for pregnant teens and women, and 2.8 µg for lactating teens and women (NIH, n.d.).

2.1.1.6 Vitamin D

Vitamin D is a fat-soluble vitamin, a steroid with hormone like activity that regulates the functions of over 200 genes, essential for growth because it is used by the body during the normal bone development and maintenance by increasing the absorption of calcium, magnesium, and phosphate (Sizar et al., 2022). There are two forms of vitamin D: vitamin D2 (ergocalciferol) and vitamin D3 (cholecalciferol) (Lips, 2006). Deficiency of the latter is linked to obesity, diabetes, hypertension, depression, fibromyalgia, chronic fatigue syndrome, osteoporosis, and neurodegenerative diseases (Naeem, 2010).

Serum/plasma (25OH)D concentration reflects the contribution from both diet and dermal synthesis and is, therefore, used as an indicator of vitamin D status (Cashman, 2020; Holick et al., 2011; Seamans and Cashman, 2009). A concentration of serum (25OH)D below 75 nmol/L has been established as vitamin D deficiency by most authors, while a cut-off of < 25 or < 30 nmol/L is considered severe vitamin D deficiency, based on the fact that the risk of osteomalacia and nutritional rickets is highly increased at those levels (Amrein et al., 2020). Subclinical vitamin D deficiency is prevalent worldwide of up to 1 billion people (Nair and Maseeh, 2012), and it may vary by age, being childhood and later stages of life when this deficiency tends to be lower; certain ethnic groups are more vulnerable than others (e.g., European Caucasians show lower rates of vitamin D deficiency compared to non-white individuals) (Cashman, 2020; Cashman et al., 2016).

From 50 to 90% of vitamin D is absorbed through the skin via sunlight; 20 minutes of sunshine daily with over 40% of skin exposed is required to prevent vitamin D deficiency (Naeem, 2010). The rest is obtained from the diet: some wild varieties of mushroom, certain varieties of algae, and foods such as egg, Cod liver oil, almon and other fatty fish, and fortified food products (e.g., milk, dairy, cereals) are the main sources of vitamin D, but the amount of this micronutrient present in food does not reflect its bioavailability because some of it remains attached to the food matrices (Maurya et al., 2020; O'Mahony et al., 2011). Besides, food processing methods and conditions (e.g., cooking temperatures, pH, oxygen, salt) can reduce the concentration of vitamin D. The limited options of foods together with significant losses during processing make it difficult to fulfil the RDA of vitamin D, which is 400-800 IU per day (Manson et al., 2016).

2.1.2 Macronutrient malnutrition

2.1.2.1 Protein

The ideal macronutrient composition of a diet to avoid diseases is still under investigation, especially for protein intake (Simpson and Raubenheimer, 2014; Solon-Biet et al., 2014). Proteins are made of amino acids (AA), and these serve as building blocks for muscles, hormones, and enzymes, among other biological functions (Boye et al., 2012). Protein malnutrition can refer either to a total lack of protein in diets or specific AA shortages. The bioavailability (i.e., the amount of AA that the body can absorb and utilize) is one of the factors that determine the quality of a protein, and it is also important to consider their source: animal proteins have high availability, but the consumption of certain animal proteins is linked to risks of higher chronic diseases (Katz et al., 2019). Besides bioavailability, for protein quality, the AA profile and digestibility are essential to determine the capacity of a food protein to satisfy metabolic demands of AA and nitrogen (Sá et al., 2020). Food protein digestibility (the quantity of protein hydrolysed by the digestive enzymes and absorbed by the organism relative to the consumed amount of protein) depends on several factors, such as protein structure, thermal processing intensity, and presence of some compounds called antinutritional factors (e.g., protease inhibitors, phytates, polyphenols, fibres, haemmagglutinins (lectins), and non-starch polysaccharides) (Duodu et al., 2003; López et al., 2018).

Populations that rely on caloric crops like sorghum, wheat, rice or maize tend to suffer from indispensable AA (e.g., lysine) malnutrition (Abelilla et al., 2018; Cervantes-Pahm et al., 2014; Shaheen et al., 2016). There are, however, other plant-based crops that contain the 20 AA, including the 9 that are indispensable (i.e., the ones that can be obtained only from the diet because the body is unable to synthetize them) (Afshin et al., 2014; Del Gobbo et al., 2015; Wang et al., 2015). Nevertheless, reduction or elimination of antinutritional compounds is critical to improve the biological utilization of plant proteins, because they have usually lower digestibility (75-80%) than animal proteins (90-95%). Plant proteins also have lower enzyme accessibility due to rigid cell walls and seed coats (Annor et al., 2017; Habiba, 2002). There are different techniques to improve the quality of the plant proteins, such as cooking, autoclaving, microwave heating, germination, irradiation, drying, fermentation, and extrusion (Sá et al., 2020). Nonetheless, one should be careful when applying heating processes to food products, because heat-labile micronutrients can be degraded, some toxic compounds can be generated, and Maillard reactions and non-enzymatic browning affect the AA bioavailability (Canniatti-Brazaca, 2006; Shimelis and Rakshit, 2005).

High protein diets are gaining popularity due to their possible beneficial effects on weight loss, preservation of muscle mass, and increased strength (Leidy et al., 2015; Westerterp-Plantenga et al., 2012). According to Naghshi et al. (2020), high protein diets might improve cardiometabolic markers, such as blood glucose and blood pressure levels. High plant protein diets decrease serum concentration of blood lipids without affecting concentrations of high density lipoprotein cholesterol and the risk of cardiovascular disease (Song et al., 2018). On the contrary, when there is a severe protein deficiency, a disease known as kwashiorkor manifests, a disease associated with children 1 to 2 years of age whose diet is based on maize, and who present general oedema, swollen abdomens, and flaky skin (Williams, 1933). Prevalence of kwashiorkor increases during times of famine, affecting mostly the rural and farming regions in Southeast Asia, Central America, Congo, Puerto Rico, Jamaica, South Africa, and Uganda (Benjamin and Lappin, 2022). Kwashiorkor occurs when there is a severe protein deficiency, but subclinical protein deficiencies are also a big issue.

Protein-energy malnutrition (PEM), derived from an inadequate dietary intake of protein, is a major health problem in developing countries (e.g., the mortality due to the PEM ranges from 25 to 30% in Saharan Africa) and it occurs because of socioeconomic, political and, occasionally, environmental factors such as natural disasters (Ahmed A Ahmed et al., 2019; Grover and Ee, 2009). Underweight (weight for age z-score < 2), stunting (height for age z-score < 2) and wasting (weight for height z-score < 2) are health problems in children under 5 years of age due to PEM and other factors (e.g., zinc deficiency is associated with stunting, infectious diseases can cause wasting). Children who suffer from underweight may be stunted, wasted or both, and these health problems impede children from reaching their physical and cognitive potential. Figure 2.2 shows the country-level prevalence stunting, wasting and underweight as reported by Ssetongo et al. (2021). Western Africa, Southern Asia, and South-eastern Asia have a significant higher estimated prevalence of undernutrition than global average estimates (Ssentongo et al., 2021).

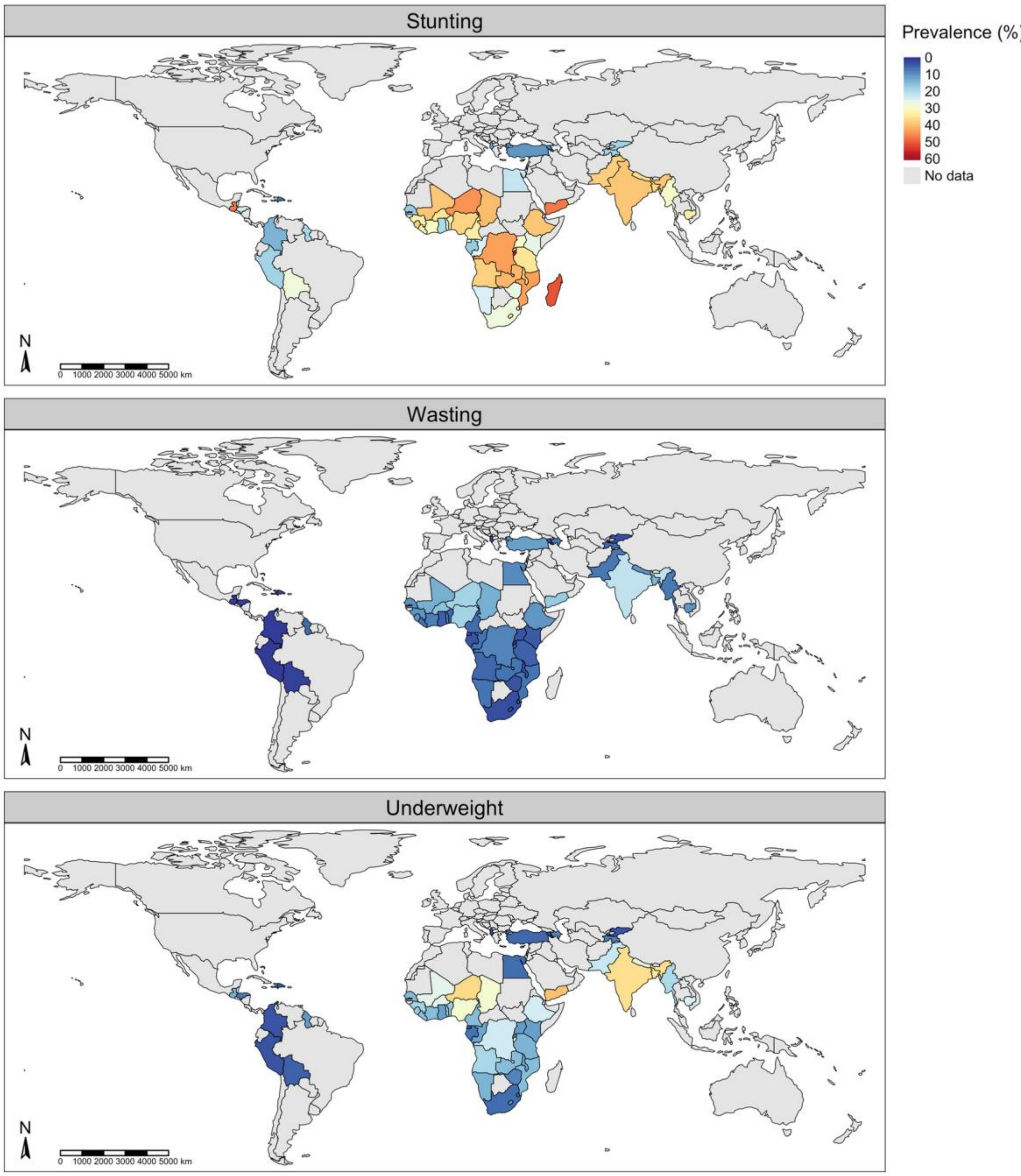

Figure 2.2 Prevalence of undernutrition (Ssetongo et al., 2021). Countries are shaded based on prevalence (%) of stunting (top), wasting (middle row) and underweight (bottom row).

2.1.2.2 Overnutrition

Overweight and obesity are defined as abnormal or excess fat accumulation that increase the risk to other health issues. The body mass index (BMI), calculated by dividing the body weight in kilograms by the square of height in meters, is used to classify overweight and obesity as seen in Table 2.1. The worldwide prevalence of childhood overweight and obesity shows an increasing trend in both developed (with 24% of boys and 23% of girls overweight or obese) and developing countries (with 13% of both boys and girls overweight or obese) (Bleich et al., 2018). With respect to adults, there are globally more overweight or obese than underweight: in 2016, 39% of men and 40% of women aged 18 and over, about 2 billion adults, were overweight, while 11% of men and 15% of women, over half a million, were obese (OECD and World Health Organization, 2020). Figures 2.3A and 2.3B show, respectively, the prevalence rates of overweight and obesity in 2015 for adult men and women aged > 20 years, by age group (Chooi et al., 2019). Men aged between 20 and 44 years tend to be more overweight than women, but after the age of 45, it was the other way around. With respect to obesity, women showed a higher rate at all ages.

The changing food environment, with ultra-processed foods (i.e., low in essential nutrients and high in added fats and sugars) being marketed as cheaper than healthier alternatives, contributes to the increasing obesity epidemic; but other factors, such as the high diffusion of information and communications technologies, automation, urbanization, aging, and other cultural social transformations have developed an obesogenic environment, where obesity-prone lifestyles are promoted (Ferretti and Mariani, 2019; Swinburn et al., 1999; Townshend and Lake, 2017). Figure 2.3C shows that the age-standardized prevalence of overweight increased from 26.5% in 1980 to 39.0% in 2015, whereas Figure 2.3D depicts an increasing trend in obesity, from 7% in 1985 to 12.5% in 2015, representing an almost 80% rise (Chooi et al., 2019). It has been estimated that 57.8% of the global population will be overweight or obese by the year 2030 if the trend does not change (Kelly et al., 2008).

Table 2.1 The international classification of adult underweight, overweight, and obesity according to BMI.

	BMI (kg/m^2)	
Classification	**Principal cut-off points**	**Additional cut-off points**
Underweight	**<18.50**	**<18.50**
Severe thinness	<16.00	<16.00
Moderate thinness	16.00–16.99	16.00–16.99
Mild thinness	17.00–18.49	17.00–18.49
Normal	**18.5–24.9**	**18.50–22.99**
		23.00–24.99
Overweight	**≥25.00**	**≥25.00**
Preobese	25.00–29.99	25.00–27.49
		27.50–29.99
Obese	**≥30.00**	**≥30.00**
Obese class I	30.00–34.99	30.00–32.49
		32.50–34.99
Obese class II	35.00–39.99	35.00–37.49
		37.50–39.99
Obese class III	≥40.00	≥40.00

Values in bold represent underweight, normal, overweight, and obese according to BMI.

Adapted from World Health Organization. Global database on body mass index.

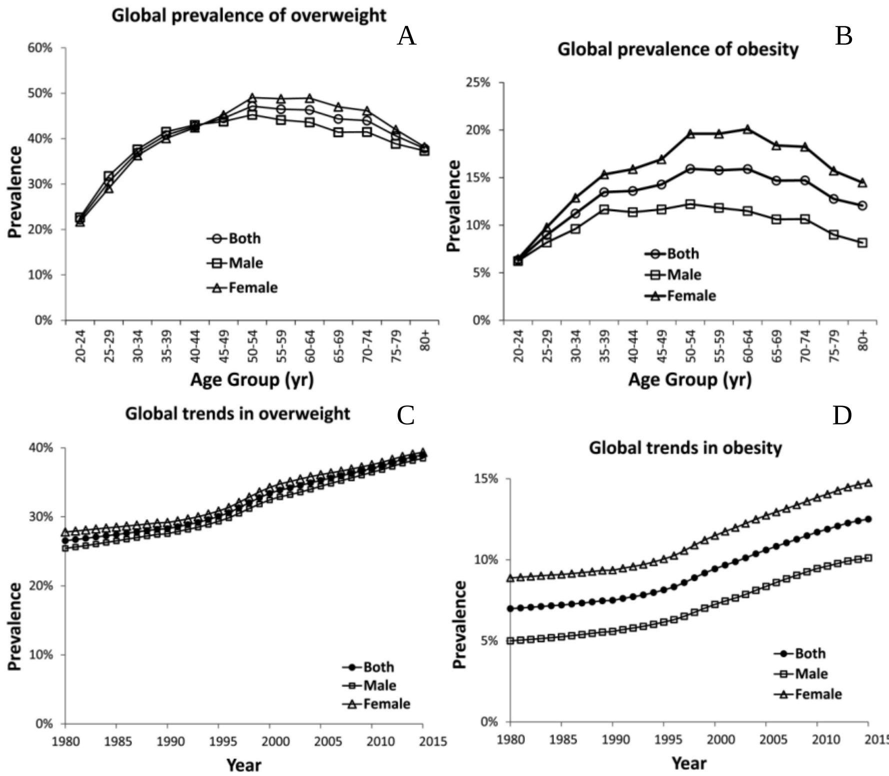

Figure 2.3 Global prevalence of overweight (A) and obesity (B) in adults > 20 years old by age group and sex, and age-standardized global of prevalence of overweight (C) and obesity (D) in men and women > 20 years old by year as reported by Chooi et al. (2019).

Overweight and obesity affect the growth and the development of children and adolescents, and these health problems are associated with physiological disorders (Rankin et al., 2016), cognitive dysfunction, impaired motor function (Wang et al., 2016), as well as altered timing of puberty (Burt Solorzano and McCartney, 2010). Overweight and obesity may also be accompanied by multiple comorbidities, such as type 2 diabetes and metabolic syndrome in youth and adults (Biro and Wien, 2010; Must et al., 1992).

Maternal overweight (BMI $\geq$ 25 kg/m^2) and obesity (BMI $\geq$ 30 kg/m^2) lead to adverse maternal and foetal complications during pregnancy, delivery, and post-partum. For instance, obese pregnant women are four times more likely to develop gestational diabetes mellitus and two times more likely to develop pre-eclampsia compared with women with a BMI within the range 18.5-24.9 kg/m^2 (Biro and Wien, 2010; Must et al., 1992).

2.2 Agriculture as a strategy to fight against malnutrition

For decades after the World War II, agriculture was focused on attempting to provide dietary energy for survival and work, by producing starchy staple crops (e.g., rice, wheat, maize, potatoes, cassava) to reduce food insecurity during the Green Revolution in South, Southeast and East Asia, ignoring the component of nutrition security (Headey and Masters, 2021). Recently, however, agriculture has been viewed as a tool not only to improve nutrition, but also to address the environmental sustainability and other development goals (e.g., reduction of both poverty and unemployment), because agriculture is the source of income of 69% of populations in low-income countries and it feeds 7.6 billion people (Fan et al., 2019). Therefore, individuals, organizations, and communities have shown interest in scaling up their efforts to link agriculture and nutrition.

Figure 2.4 shows how agriculture is linked not only to caloric energy but also to macronutrients and micronutrients required for proper growth. It is important to note that non-dietary pathways can play an important role when attempting to reduce malnutrition. Households' assets and economic activities have the potential to raise income, which can be used for food and non-food purchases, as shown in Figure 2.4. Households, ideally, use their income to acquire safe, healthy, and diverse foods, as well as health services and education, all of which improves their nutritional status. There are, however, unhealthy choices, such as ultra-processed foods that contribute to malnutrition and overweight or obesity, that people purchase due either to a lack of awareness about balanced diets or to the high prices of healthy food products. Therefore, nutrition education and behaviour change communication programs may be required along with policies that ensure affordable healthy food products.

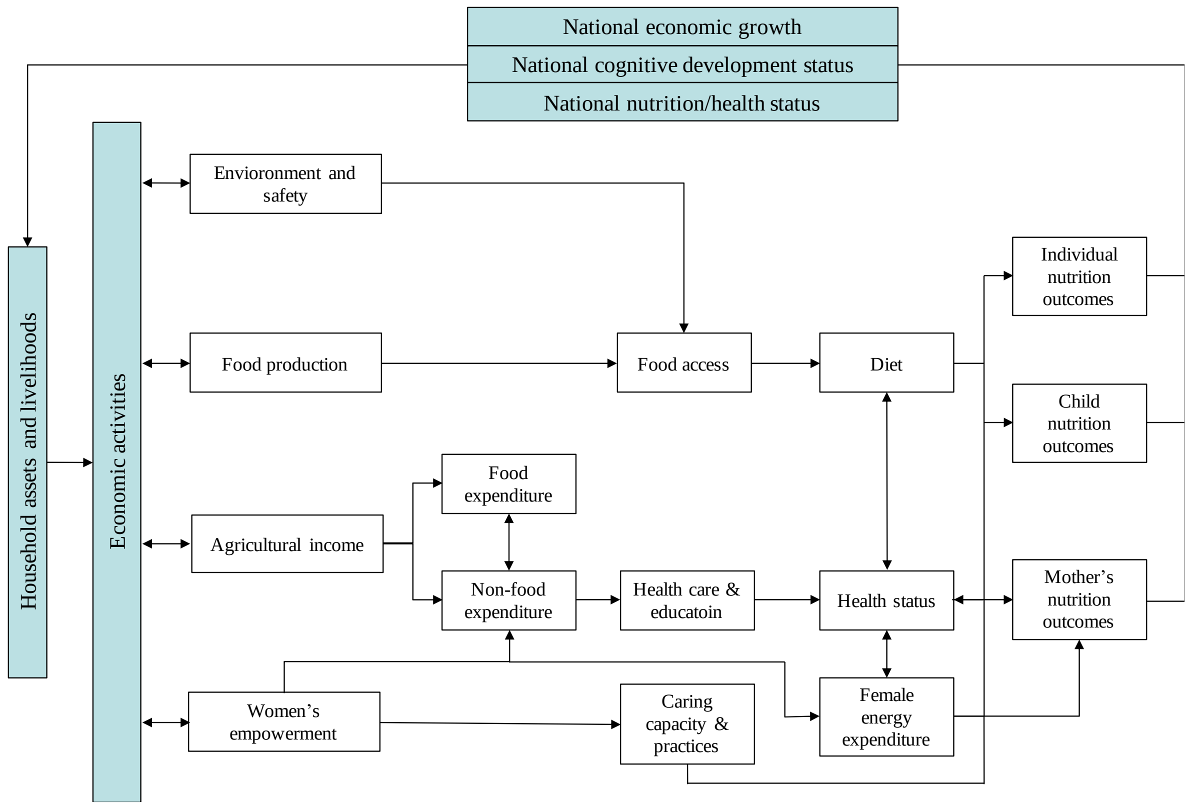

Figure 2.4 A conceptual framework of linking agriculture to nutrition as suggested by Fan et al. (2019).

Through their second aim, the United Nations' Sustainable Development Goals (SDGs) focus on the convergence of agriculture and nutrition. SDG 2 - Zero Hunger combines agriculture and nutrition into one target, aiming to eradicate hunger, to ensure food security and enhanced nutrition, and to promote sustainable agriculture (Canavan et al., 2016). Table 2.2 contains relevant definitions regarding food and nutrition security. The Rome Declaration on Nutrition, issued at the International Conference on Nutrition 2 in 2014, recognized that food systems, including agriculture, play a role in delivering healthy, diverse, and balanced diets, advocating for investments in small-scale agriculture as a mean of combating hunger (Fan et al., 2020).

Table 2.2 Definitions of some terms regarding food security.

Term	**Definition**	**Source**
Food security	Food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life	(FAO, 1996)
Nutrition security	Nutrition security can be defined as adequate nutritional status in terms of protein, energy, vitamins, and minerals for all household members at all times	IFPRI, 1995 *in* Committee on Wolrd Food Security (2012)
	Nutrition security exists when food security is combined with a sanitary environment, adequate health services, and proper care and feeding practices to ensure a healthy life for all household members	World Bank, 2006 *in* Committee on Wolrd Food Security (2012)
	Nutrition security exists when all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, education and care	FAO/AGN, 2012 *in* Committee on Wolrd Food Security (2012)
Food and nutrition security	Food and nutrition security is achieved when adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for and satisfactorily used and utilized by all individuals at all times to live a healthy and active life	UNICEF, 2008 in Committee on World Food Security (2012) (Committee on Wolrd Food Security, 2012)

Food and nutrition security exists when all people at all times have physical, social and economic access to food of sufficient quantity and quality in terms of variety, diversity, nutrient content and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, education and care	FAO/AGN, 2011 in Committee on World Food Security (2012) (Committee on Wolrd Food Security, 2012)

2.2.1 Nutrition-sensitive agriculture (NSA)

The term of nutrition-sensitive agriculture (NSA) has been coined to refer to an approach that aims to produce, in a sustainable manner, a wide variety of affordable, nutritious, culturally appropriate and safe foods in sufficient quality and quantity to meet the dietary requirements of a population (FAO, 2017). For food systems to be sustainable, they should operate within planetary boundaries, that is the absolute environmental limits for natural resource use and emissions that should be respected to avoid major and irreversible earth system change when developing foods and diets (Ridoutt et al., 2021). A sustainable diet can be defined as a diet with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations (Burlingame et al., 2012). Sustainable dietary patterns should not only consider the greenhouse gas emissions, but also data for land and water use, and occasionally nitrogen and phosphorus application, and effects of agriculture on biodiversity (Steenson and Buttriss, 2020).

The ultimate goal of an NSA project is to improve the nutritional status by addressing the underlying causes of nutrition (e.g., access to safe and nutritious food, nutrition knowledge and norms, income, women's empowerment) (Herforth and Ballard, 2016). Dietary diversification is key when trying to improve the intake of several nutrients simultaneously, and it takes several approaches at community or household level, such as agricultural interventions, production and promotion of animal-source foods through animal husbandry or aquaculture, processing strategies at the commercial or household level to enhance micronutrient absorption from plant-based diets (e.g., food fortification), nutrition education to promote the dietary diversification (Gibson and Anderson, 2009). NSA projects, when properly designed (e.g., adequate metrics and indicators, such as anthropometric measures or food access parameters, are used to determine their success based on the stated nutrition objectives) and supported by key sectors, have shown to improve a variety of diet and nutrition outcomes in mothers and children, especially when they include components of behaviour change communication and women's empowerment (Ruel et al., 2018).

Different metrics can gather data when assessing the chosen indicators. For instance, if diet quality is to be determined, there are dietary assessment instruments: 24-h dietary recall (24HR), food record (FR) (a.k.a. food diary), food frequency questionnaire (FFQ) and screeners (SCR). Each metric measures different aspects of diet quality. 24HR, for example, obtains detailed data about all foods and beverages consumed on a given day, whereas the FFQ obtains frequency and, in some cases, portion size information about food and beverage consumption over a specific period, typically the past month or year. Utility and limitations of data obtained by each instrument, and a comprehensive comparison among them are available (NIH, n.d.). For instance, the FR is for cross-sectional and prospective studies, whereas 24H, FFQ and SCR are used for interventions.

2.3 Multi-criteria decision analysis and its role in agriculture related topics

As previously mentioned, there are numerous types of NSA interventions, as well as metrics and indicators to measure their impact. When designing an NSA intervention, the context of the community should be considered, and the nutrition objectives should be incorporated, making the design a difficult task that can be facilitated with multi-criteria decision analysis

(MCDA). MCDA involves different methods that support the decision maker in their unique and personal decision process, providing stepping-stones and techniques for finding a solution (Ishizaka and Nemery, 2013). MCDA methods place the decision maker at the center of the process, incorporating subjective information, which is also known as preference information.

2.3.1 The process of MCDA

The MCDA process is embedded in a wide process that involves different stages: 1) problem identification and structuring, 2) model building and use, and 3) the development of action plans, as described by Belton and Stewart (2002):

2.3.1.1 Problem structuring

This phase consists of rationalizing an issue, identifying key concerns, goals, stakeholders, actions, uncertainties, etc. In other words, problem structuring is the identification of the factors and issues that should be discussed and analyzed. This process may be informal, supported by one general managerial tool (e.g., SWOT: strength, weaknesses, opportunities, threats; SODA: Strategic Options Development and Analysis).

During this phase, it is important: 1) to generate ideas and capturing them (e.g., thinking about specific actions or alternatives, environmental factors and constrains), and 2) to structure those ideas (e.g., through cognitive mapping, which aims to present the problem/issue as a decision maker perceives it, in the form of means-ends network-like structure).

2.3.1.2 Model building and use

This phase should be a dynamic process, informed by and informing the process of problem structuring, and interacting the process of evaluation. It may involve iteration, search for new alternatives and criteria, discarding, reinstating, and redefining of old ones, and further extensive discussion among the participants.

The key elements of the model framework are:

1. Alternatives (e.g., options, strategies, action plans). When an intervention starts with a general approach to problem solving, potential alternatives will emerge. These should be elaborated to create well defined options for evaluation, as well as to perform an exercise of crude prioritization to establish which ones are of great interest. In order to do so, there are different methods, such as the Analysis of Interconnected Decision Areas (AIDA) to define feasible combination of actions prior to evaluation, or EQUITY, a decision support tool that helps assessing different levels of investment areas across a number of decision areas where each individual element is assessed on a cost and benefit scale.
2. Model of values (e.g., criteria, objectives, goals). An initial candidate set of key factors or criteria will be derived from the problem structuring phase. The considerations to consider in all MCDA methods are (a) *value relevance* (i.e., linking the concept to goals, thereby enabling them to specify preferences directly related to the concept), (b) *understandability* (i.e., decision makers understand the concepts that will be analyzed), (c) *measurability* (i.e., degree of measurement of the performance of the alternatives against specified criteria), and (d) *non-redundancy* (i.e., making sure that no more than one criterion measures the same factor), (e) *judgmental independence* (i.e., criteria are not judgmentally independent if preferences with respect to a single criterion, or trade-offs between two criteria

depend on the level of another, (f) *balancing completeness and conciseness* (i.e., all important aspects of the problem are captured in a concise manner, keeping the level of detail to the minimum required), (g) *operationality* (i.e., the model is usable with reasonable effort—the information required does not place excessive demands on the decision makers), and (h) *simplicity versus complexity* (i.e., the criteria set itself is a simple representation that captures the essence of the issue, which has been extracted from a complex problem description).

3. Stakeholders. Once identified, stakeholders can be classified based on their level of interest and power with respect to an issue. It is important not only considering stakeholders in isolation, but also examining their potential influence on other stakeholders as well as possible coalitions.
4. Uncertainties. Increased effort in problem structuring and in collecting and analyzing data can improve the understanding of the nature of uncertainty and may reduce it in some cases, but cannot eliminate it. Therefore, any MCDA method should pay attention to how to handle uncertainty. It is useful to differentiate between internal uncertainty (relating to the process of problem structuring and analysis) and external uncertainty (regarding the nature of the environment and thereby the consequences of a particular course of action).

2.3.1.3 Development of action plans

MCDA is concerned not only with the analysis, but also with the implementation of results, which means translating the analysis into specific plans of action. Scenario planning is a technique that facilitates the process of identifying uncertain and uncontrollable factors that may affect the consequences of the decisions in the strategic management context. The approach of scenario planning is extended to an analytical process of designing, evaluating, and selecting courses of action on the basis of robustness to uncertainties, which suggests close parallels with MCDA (Goodwin and Wright, 2001). The five principles for scenario construction, according to Van der Heijden (2005), are the following:

1. At least two scenarios are required to reflect uncertainty, but more than four has proved to be impractical;
2. Each scenario should be seen to evolve logically from the past and present;
3. Each scenario must be internally consistent;
4. Scenarios must be relevant to the client's concerns and they must provide a useful, comprehensive and challenging framework against which the client can develop and test strategies and action plans;
5. The scenarios must produce a novel perspective on the issues of concern to the client.

Once the scenarios are built, they are meant to be tools to explore and to evaluate alternative strategies for the organization.

2.3.2 MCDA methods and types of problems

MCDA involves mathematics, management, informatics, psychology, social science and economics (Ishizaka and Nemery, 2013). According to Ogrodnik (2019), MCDA can either make use of aggregation methods (e.g., analytic hierarchy process (AHP), multi-attribute utility theory (MAUT)), surpassing methods (e.g., elimination and choice expressing the reality (ELECTRE), preference ranking organization method for enrichment evaluations (PROMETHEE)), geometric distance methods (e.g., the Technique for Order Preference by Similarity to Ideal Solution

(TOPSIS), multi criteria optimization and compromise solution (VIKOR)), interactive methods (e.g., RUBIS) or verbal decision analysis methods (e.g., ZAPROS).

MCDA can solve different types of problems (Table 2.3): choice (e.g., a manager selecting the right person for a particular project), sorting (e.g., classifying employees into performance categories such as “outperforming”, “average-performing” and “weak-performing”), or ranking problems (e.g., ranking universities according to several criteria) (Ishizaka and Nemery, 2013).

Table 2.3 MCDA methods and problems (Ishizaka and Nemery, 2013).

Choice problems	**Ranking problems**	**Sorting problems**	**Description problems**
AHP	AHP	AHPSort	GAIA
ANP	ANP	UTADIS	FS-Gaia
MAUT/UTA	MAUT/UTA	FS	
MACBETH	MACBETH	ELECTRE-Tri	
PROMETHEE	PROMETHEE		
ELECTRE I	ELECTRE III		
TOPSIS	TOPSIS		
Goal Programming	DEA		
DEA			

Each MCDA method has its own limitations, particularities, hypotheses, premises and perspectives, and it is subsequently not possible to determine whether one method makes more sense than another in a specific problem situation (Ishizaka and Nemery, 2013). There are, however, some ways of choosing appropriate MCDA methods to solve specific problems. One way is to look at the data and parameters of the method and the modelling effort, as well as looking at the outcomes and their granularity as supported by Guitouni et al. (1999). Table 2.4 shows the outcomes as well as the required inputs for the MCDA ranking or choice methods.

Table 2.4 Required inputs for MCDA ranking or choice methods (Ishizaka and Nemery, 2013).

Inputs	**Effort input**	**MCDA method**	**Output**
Utility function	Very high	MAUT	Complete ranking with scores
Pairwise comparisons on a ratio scale and interdependencies	↑	ANP	Complete ranking with scores
Pairwise comparisons on an interval scale		MACBETH	Complete ranking with scores
Pairwise comparisons on a ratio scale		AHP	Complete ranking with scores
Indifference, preference and veto thresholds		ELECTRE	Partial and complete ranking (pairwise outranking degrees)
Indifference and preference tresholds		PROMETHEE	Partial and complete ranking (pairwise preference degrees and scores)
Ideal option and constraints		Goal programming	Feasible solution with deviation score
Ideal and anti-ideal options		TOPSIS	Complete ranking with closeness score
No subjective inputs required	↓ Very low	DEA	Partial ranking with effectiveness score

2.3.3 Studies where MCDA has been used in agriculture

Regarding agriculture-related topics, MCDA has been used to resolve complex problems, such as soil erosion and degradation. Grau et al. (2010) applied different methods (i.e., ELECTRE I, initial PROMETHEE, weighted PROMETHEE, and AHP) to prepare an integral plan to ameliorate and/or solve the problem of desertification and erosion. Decision matrixes were built with five alternatives (i.e., autochthonous forest, high value forest, traditional farms, erosion control crop with agriculture use, and erosion control crop with industrial use (biomass)), and eight criteria (i.e., water erosion, eolian erosion, implementation facility, water resources, economic benefits, hand power, environmental impacts, and social acceptance). The authors found a high level of consistency among the three MCDA methods used despite the complexity of the system.

MCDA has also been used to measure the sustainability level of agricultural systems. To assess the level of sustainability of agricultural practices in the coastal zone of Bangladesh, Talukder et al. (2016) measured indicators of productivity, stability, efficiency, durability, compatibility and equity, and, to aggregate them, they used the Multi-Attribute Value Theory (MAVT), a simplification of MAUT in that, unlike MAUT, MAVT does not seek to model the decision maker’s attitude to risk (Belton, 1999). Using composite indicators from the same categories, agricultural systems of southwest coastal Bangladesh were evaluated and ranked in terms of agricultural sustainability (Talukder et al., 2018). These studies prove that MCDA approaches represents a promising tool for agricultural sustainability assessment.

Król et al. (2018) evaluated and ranked the climate change adaptation practices regarding tillage for maize cultivation in Poland, adopting criteria for 3 dimensions: environmental (i.e., soil organic carbon, and soil moisture), financial (mean gross profit, and standard deviation gross profit), and socio-economic (labor in hours, and fuel in litters). The authors used an integrated approach, combining AHP and PROMETHEE to achieve operational synergies. AHP facilitated the criteria ranking and weighting, and the preferences were conveyed to PROMETHEE to select the most efficient alternative for the decision-maker. The findings from this study can be useful for policy suggestions on tillage practices in maize and other crops, considering the context of the region or country where the methodology is to be applied.

Henríquez-Antipa and Cárcamo (2019) developed a survey to perform a pairwise comparison multicriteria analysis using AHP to determine the relative priority of high-level dimensions (i.e., social, economic, technological, environmental, and institutional) for the implementation of seaweed aquaculture in Chile, and a second survey to determine the SWOT factors to develop a quantified SWOT-AHP analysis. This study was useful to interpret stakeholders' multidimensional perceptions on policy implementation gaps regarding the current status of Chilean small-scale seaweed aquaculture.

MCDA has also been combined with geographic information systems for finding suitable zones of peri-urban agriculture, using several criteria (i.e., primary workers, percentage of agricultural workers, percentage of vegetation, piped water supply, availability of drainage facility, having market facility, availability of bus services, and distance from the railway) (Majumdar, 2020). To determine weight and values of the criteria, Musakwa (2018) used the group AHP, and they developed a strategically located land index to identify areas suitable for agricultural land reform in South Africa. Seyedmohammadi et al. (2018), on the other hand, used AHP and fuzzy AHP for weighting the criteria, and they used simple additive weighting, TOPSIS and fuzzy TOPSIS for cultivation priority planning of maize, rape, and soybean crops in land units. These studies suggest that integrating these frameworks in the planning policies of agriculture in developing countries as a tool for land use planning can improve the control over soil, land, and environmental losses.

Ardakani et al. (2017) applied the TOPSIS method to build a dynamic quantitative national-level food and nutrition security index to be used as a benchmark for the dimensions of food and nutrition security and prioritize the vulnerabilities of food system in the delivery of food and nutrition security in Iran. It is fair to say that MCDA is a powerful tool with the potential to help design better NSA projects. TOPSIS, specifically, has the advantage that the amount of effort needed during input is relatively low, and thus offers a complete ranking with closeness scores (Table 2.4).

2.3.4 MCDA suggested for the design of NSA interventions

As mentioned above, there are several types of NSA interventions grouped into 5 key functions of the food system. The decision on what pathway(s) to follow towards improving the nutritional status depends on the context of the community (e.g., the agricultural practices that they perform, the health status or the educational status of different segments of the population, what is considered culturally appropriate) where the project is to take place. Therefore, the selection of the indicators to determine the success (or failure) of an intervention also depends on the context of the community, because it is important to measure the impact at each step of the full pathway. There are too many indicators, and it can be difficult to track what each one reflects, which may lead to misinterpretations (e.g., an indicator that measures food access can be wrongly chosen to determine diet quality). Besides, several metrics and technological tools are available to the required data for each indicator. Surprisingly, MCDA has not been used to design NSA interventions. Therefore, we suggest it as a promising tool for that purpose.

2.4 Conclusion

In the past, agriculture was more concerned with improving the yields of calorically dense crops, such as rice, wheat and maize, neglecting the production of fruits, vegetables, pulses, nuts and other crops that provide with vitamins, minerals and essential amino acids. Besides, food policies have allowed the production of ultra-processed food products, which are high in fats and sugars. These situations may have led to the reduction of starvation and famine as causes of malnutrition, but other issues of malnutrition persist in the world.

Many developing countries face the double burden of malnutrition: micronutrient deficiencies that may cause other health problems (e.g., stunting), and overnutrition as overweight and obesity. Fortunately, agriculture has been evolving into an approach that not only takes into account the energy needs of the population, but also the nutritional components: the nutrition-sensitive agriculture. Nutrition-driven agricultural policies, programs, investments and strategies can be attained if nutrition is proactively incorporated into their design (i.e., using clear and measurable outcomes to measure the positive or negative impact on the community where a project is to take place). Due to the complexity of nutrition-sensitive agriculture projects, MCDA methods could be helpful to facilitate the task of designing interventions, especially the TOPSIS method because of its low amount of effort needed during input, and the complete ranking with closeness scores that it delivers.

CONNECTING TEXT

A comprehensive review of literature, which has been prepared for submission to *Nutrition Research Reviews*, showed that different forms of malnutrition have been associated with low- and middle-income settings. Since a significant sector from poor and rural communities worldwide work on agricultural activities, agriculture can be a key strategy to fight against malnutrition. Agriculture has been evolving, from focusing on production of caloric staple crops to an approach that considers crops rich in vitamins, minerals and/or essential amino acids, as well as other aspects (e.g., women's empowerment, nutrition education): nutrition-sensitive agriculture (NSA).

Chapter III addresses the first two objectives of this thesis (i.e., to analyze the full pathway(s) that the different types of NSA interventions may follow towards improving the nutritional status of vulnerable communities, and to determine the current tools that are used for the measurement of the full pathway of change from agricultural inputs and practices to nutrition outcomes), as well as the potential use of multi-criteria decision analysis (MCDA) for the design of NSA interventions.

A paper based on Chapter III has been published by *Critical Reviews in Food Science and Nutrition*. The manuscript is co-authored by Dr. Michael Ngadi (my supervisor), Dr. Christopher Kucha, and Dr. Ebenezer Kwofie. The format of the original manuscript has been modified to remain consistent with the thesis format. All the literature cited in Chapter III can be found in chapter XI (General References).

III. DESIGNING NUTRITION-SENSITIVE AGRICULTURE (NSA) INTERVENTIONS WITH MULTI-CRITERIA DECISION ANALYSIS (MCDA): A REVIEW

3.1 Abstract

Despite the efforts to end malnutrition through intensive agriculture of caloric crops, micronutrient deficiencies and other forms of malnutrition persist in vulnerable communities worldwide. Nutrition-sensitive agriculture (NSA) interventions are recognized as chances to address the causes of malnutrition. In this work, the different types of NSA interventions were explored, as well as the pathways through which they can improve nutrition (e.g., increasing biofortified crops and income generation via agricultural sales for a positive impact on access to nutritious foods, and simultaneously involving nutrition education to improve care practices and eventually nutritional status). Some NSA interventions focus on one pathway. Well-designed interventions, however, should follow multi-pathway approaches targeting the underlying causes of undernutrition within the selected population. The circumstances in which certain indicators should be used to measure the impact of an NSA intervention in each stage of the full pathway were also explained, as well as the need of enhancing the design of such interventions. Multi-criteria decision analysis (MCDA) has been employed to solve agriculture-related issues, but it has not been used to identify the optimal types of NSA interventions, metrics, and indicators based on the context of the community, priorities and objectives of the project managers and designers, etc.

Keywords: double burden of malnutrition (DBM); nutrition indicators; food system

3.2 Introduction

Undernutrition affects almost 40% of the global population: 2 billion people suffer from one or more types of micronutrient deficiencies (a.k.a. hidden hunger), and almost 800 million people suffer from energy deficiency, being pregnant or lactating women and infants and young children the most vulnerable ones (IFPRI, 2016; Maleta, 2006). Poor dietary quality contributes to malnutrition, especially in low- and middle-income countries; low-income settings lead to the consumption of staples with low availability of vitamins, minerals and other essential nutrients (Green et al., 2016; Kennedy et al., 2007). This happens when agriculture policies rely heavily on improving yields of staple grains, while neglecting fruit, vegetable, pulse and nut crops that are essential to fight malnutrition (DeFries et al., 2015).

Agriculture is the main occupation of 80% of poor populations in rural areas; it provides food, livelihoods and income (Ruel and Alderman, 2013). Therefore, nutrition-sensitive agriculture (NSA) has been suggested as a solution to eradicate malnutrition; NSA seeks to ensure the production of a variety of affordable, nutritious, culturally appropriate, and safe foods in adequate quantity and quality to meet the dietary requirements of a population (FAO, 2017). Enhancing the nutritional status can be achieved through different pathways, such as impacting diet quality or care practices. Well-designed, targeted, and implanted nutrition-sensitive programs will be successful if they integrate health components from different sectors (e.g., agriculture, women's empowerment, water, sanitation and hygiene) rather than nutrition issues alone. Despite the efforts to make agriculture nutrition-sensitive, there are still some gaps.

One of the gaps is that there are too many indicators but the full pathway of change from agricultural inputs and practices to nutrition outcomes is rarely properly measured (Herforth and Ballard, 2016). The most appropriate indicators for a project vary, depending on the nature of the agriculture-nutrition intervention, and it is difficult to keep track of what a specific indicator does and does not reflect. Verger et al. (2019) found that misleading results are shown in some NSA studies because the authors interpreted, for instance, household dietary diversity score (HDDS) as a direct measure of diet quality, household nutrition or nutritional status, when it is actually a measure of food access. The inappropriate selection of outcome indicators has contributed to a lack of empirical evidence to demonstrate impact within the time frames and sample sizes of current projects (Hawkes et al., 2012).

Defining appropriate pathways and choosing suitable metrics and indicators to measure them can be overwhelming tasks. Therefore, it is necessary to develop new approaches and holistic models for the integration of multicriteria tools with which one can select pathways, metrics, and indicators based on the context of a community where an NSA intervention is to be applied. The multicriteria decision analysis (MCDA) has been used to solve complex nutrition-related issues, and it has the potential to facilitate the design of NSA interventions. The objectives of this work were 1) to discuss the relevance of the different types of NSA interventions, 2) to highlight the importance of integrating a multi-pathway approach in their design, 3) to describe the metrics and tools that are used to collect data from NSA projects, 4) to describe the indicators that typically measure the impact of NSA interventions and 5) to examine the potential of MCDA to solve agriculture-related issues, including the design of NSA interventions.

3.3 Types of nutrition-sensitive agriculture (NSA) interventions within a food system

A food system can be defined as the collection of all the elements (environment, people, inputs, processes, infrastructure, institutions) and activities related to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities;

consequently, food systems are influenced by sociocultural, economic, political and environmental contexts (Branca et al., 2019). The different forms of malnutrition occur when food systems are incapable of delivering nutritious, safe, affordable, and sustainable diets or, in a worse scenario, when those food systems undermine nutrition (e.g., aggressive marketing of formula and baby foods affecting breastfeeding and feeding practices for young children). Therefore, NSA interventions are needed to make it possible for populations to have access to healthy diets. A healthy diet, as defined by (Neufeld et al., 2023), provides, without excess, adequacy of nutrients and health-promoting substances from nutritious foods and avoids the consumption of health-harming substances, preventing diseases. As seen in Figure 3.1, there are several types of interventions, categorized into four key functions of the food system, and cross-cutting issues; there are NSA projects that cover more than one function, but are classified according to the primary entry point (FAO, 2017). The types of NSA interventions affect different outcomes. Table 3.1, as adapted from FAO (2016), is a matrix that provides some ideas of how the NSA interventions may contribute to the outcome areas: on-farm food availability and diversity; food environment in markets; income; women's empowerment; nutrition knowledge and norms; and natural resource management practices. The areas from Table 3.1 highlighted in green represent the pathways that certain NSA interventions can impact; the areas highlighted in yellow are the potential pathways that can be impacted when designed using a multi-pathway approach; the blank areas imply that the NSA interventions do not affect those outcomes, unless some complementary, more nutrition specific intervention is added. In this section, the relevance of the types of interventions from each food system function and the cross-cutting issues is explored.

Table 3.1 Matrix of food system functions and types of NSA interventions.

Food system function	Types of NSA interventions	On-farm food availability & diversity	Food environment in markets	Income	Women's empowerment	Nutrition knowledge and norms	Natural resource management practices
Food production	Diversification and sustainable intensification of agricultural production	Meet dietary gaps through own production	Increase availability and affordability of nutritious foods and diets in markets	Increase equitable access to resources and income; reduce poverty	Increase women's access to resources, know-how and income; reduce labor and time burden	Increase awareness/behavior change communication (BCC) of nutritious foods and diets	improve food safety, e.g., by good agricultural practices
	Nutrition-sensitive livestock and fisheries						
	Biodiversity for food and nutrition						
	Biofortification						
	Urban and peri-urban agriculture						

Food handling, storage and processing	Nutrition-sensitive post-harvest handling, storage and processing Food fortification	Increase on-farm and off-seasonal availability of targeted nutritious crops	Increase variety in local markets, reduce prices & postharvest losses & improve convenience of nutritious foods	Increase income from value additional and technical expertise; reduce poverty	Increase women's access to resources, know-how and income; reduce labor and time burden	Increase awareness/ BCC of nutritious foods and diets and retaining nutrient content	Improve food safety and food standards, e.g., by good manufacturing practices
Food trade and marketing	Trade for nutrition Food marketing and advertising practices Food price policies for promoting healthy diets Food labelling	Increase on-farm and off-seasonal availability of targeted nutritious crops	Increase variety in local markets, reduce prices & postharvest losses & improve convenience of nutritious foods	Increase income from value additional and technical expertise; reduce poverty	Increase women's access to resources, know-how and income; reduce labor and time burden	Increase awareness/ BCC of nutritious foods and diets and retaining nutrient content	
Consumer demand, food preparation	Income generation for nutrition	Increase crop productivity and diversity food		Increase equitable access to resources and	Enable equitable decision-making;		

and preferences		subsidies & distribution; household gardens		income; reduce poverty	increase women's access to resources, know-how and income; reduce labor and time burden		
	Nutrition education and behavior change communication		Strengthen storage, processing and retail of nutritious foods in markets			Increase nutrition knowledge/BCC including awareness of healthy diets	
	School food and nutrition						
	Nutrition-sensitive social protection			Increase equitable access to resources and income; reduce poverty			
	Nutrition-sensitive humanitarian food assistance						
Cross-cutting issues	Nutrition-sensitive value chains	Increase on-farm and off-seasonal availability of targeted	Increase variety in local markets, reduce prices & postharvest losses & improve	Increase income from value additional, technical expertise and	Enable equitable decision-making; increase women's access		Improve food safety and food standards; reduce risk of waterborne and vector-borne
	Food loss and waste: prevention,						

	reduction and management	nutritious crops	convenience of nutritious foods	reduced food wastes and losses; enables savings and strategic investments; reduce poverty	to resources, know-how and income; reduce labor and time burden		disease; reduce environmental risks for food items (contamination)
	Women's empowerment and gender equality						
	Food quality, safety and hygiene						

The green-shaded areas represent important entry points to leverage and measure, while yellow-shaded areas are potential contribution requiring attention and should be measured if addressed. The blank spaces are typically less of a direct contribution, although linkages may be possible, and can be measured to ensure no harm.

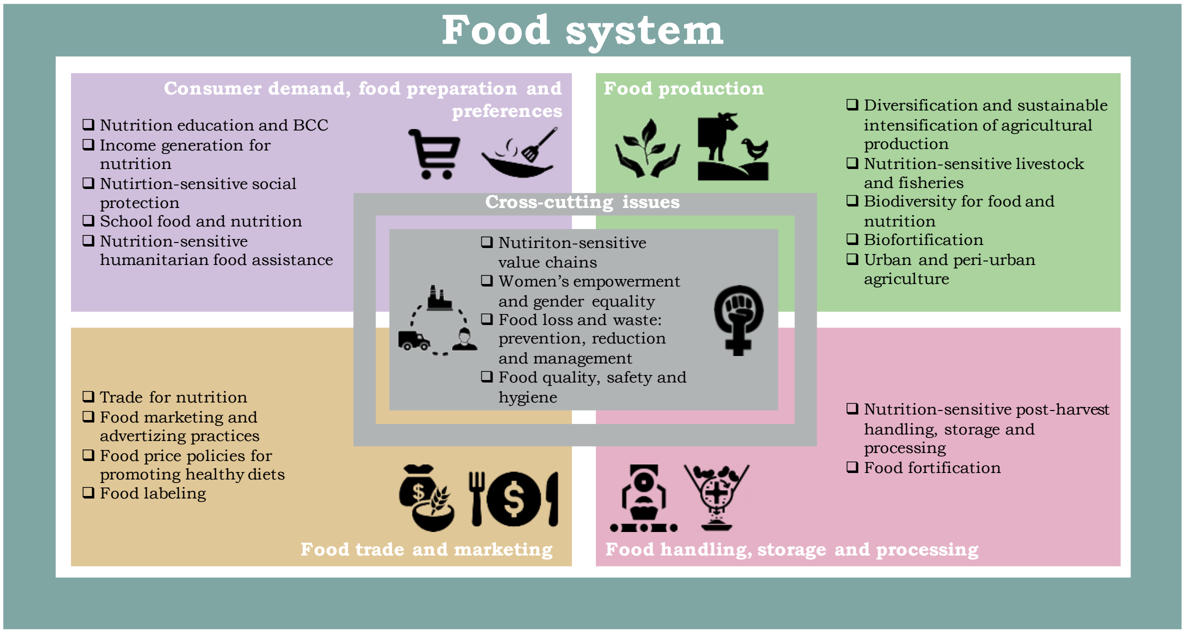

Figure 3.1 Nutrition-sensitive agriculture (NSA) interventions within the five key functions of a food system.

3.3.1 Food production

Diversification and sustainable intensification of agricultural production is the first in the list of interventions from food production. The objective of the sustainable intensification is to produce more food from the existing land base with reduced environmental impacts (Kurgat et al., 2018). The adoption of sustainable intensification farm practices (e.g., integrated organic and inorganic nutrient management, conservation agriculture, integrated pest management, crop diversification and sustainable irrigation) improves yields and nitrogen use efficiency, and has the potential to conserve resources (Pretty et al., 2011; Teklewold et al., 2013). The principles of sustainable intensification and diversification can be applied at different scales: from the national and regional level to a home garden. There is still a tendency to invest in starch-rich crops (e.g., maize, wheat, and rice), even when their nutrition profile is poorer compared to that of other crops;

sweet potato, potato, wheat, lentil, common bean and chickpea are among the nutrient-rich crops that are generally overlooked, even when these are promising under climate change (Manners and van Etten, 2018). The need of diversifying agricultural crops to enhance the human nutrition may seem an obvious option but increasing agricultural diversity alone does not guarantee the delivery of nutritious foods to the individuals in vulnerable communities. Rosenberg et al. (2018), for example, noted that child diets and nutrition were not necessarily improved by the increased agricultural diversity in rural Zambia. Subsistence and market-oriented mechanisms may explain how diversification affect dietary diversity: in places with high levels of biodiversity, diversifying the food production is associated with lower diet diversity due to forgone income from specialization in one or only a few cash crops (Sibhatu et al., 2015). Agricultural diversification among farms with low agricultural biodiversity benefits diets through subsistence pathway: on-farm species diversity has been positively associated with the number of food items consumed from own production, meaning less dependence on purchased foods (Dewey, 1981; Oyarzun et al., 2013).

Nutrition-sensitive livestock and fisheries is another type of food production interventions. Terrestrial animal source foods offer a wide range of essential macronutrients and micronutrients, indispensable for human growth and development. Apart from protein, terrestrial animal source foods provide essential fatty acids, such as the arachidonic, docosahexaenoic, and eicosatetraenoic acids, which have vital roles in neurodevelopment, anti-inflammatory processes and cell-membrane integrity; or the docosapentaenoic and Omega-6 acids, which have shown potential reduction of non-communicable disease risk (FAO, 2023; Hadley et al., 2016; Swanson et al., 2012). Protein is an important part of a basic diet, but an estimated of one billion people in the world suffer from protein deficiency (Gakpo, 2020). Livestock animals are a good source of digestible a and essential amino-acids. The utilizable protein (i.e., bioavailable for digestibility) has been negatively associated with child stunting, and the essential amino-acids are fundamental for the growth and neurocognitive development of young children (Ghosh et al., 2012; Parikh et al., 2022; Semba et al., 2016). Regarding the micronutrients, terrestrial animal source foods provide with B vitamins, especially B12 (cobalamin), which is absent in plant based foods, and plays a role in cellular metabolic processes, and its deficiency may lead to pernicious anemia and compromised neurodevelopment and brain function (Green et al., 2017). Minerals, such as zinc and iron, are available in the muscle tissue of meats, and the deficiency of these minerals has a significant impact on the global burden of disease (Black et al., 2013). The contribution of livestock animal source foods to nutrition depends on the production systems. For instance, the breed of an animal and its individual genetic traits, as well as other intrinsic characteristics, such as sex and age, may affect the quality of the macronutrients; the diet of the animal has also an effect on the nutritional quality of the ensuing terrestrial animal food, whereas husbandry practices have an impact on safety, organoleptic, and technological food-quality attributes (FAO, 2023).

One problem with livestock animals is that they already occupy 70% of the agricultural land, and it is expected to reach 76% by mid-century (van Huis, 2020). Therefore, other alternatives are encouraged, and insects represent a good one because their production emits fewer greenhouse gases, needs less water and land than common livestock species, and can be grown on organic side streams of low economic value (van Huis, 2020). Insects are poikilothermic, which is why they may reach a high feed conversion efficiency (van Huis and Oonincx, 2017). Nevertheless, to reach high efficiency, optimal diets are required. Some insect species accumulate protein very efficiently: whereas poultry provided with optimized diets converts 33% of dietary protein to edible body mass, yellow mealworms utilize 22–45% of dietary protein, black soldier fly larvae about half (43–55%), and Argentinean cockroaches 51 to 88% (van Huis and Oonincx, 2017). These data illustrate that the starting level of protein efficiency, without optimizing genetic background or diets, is already high compared to conventional livestock. Although farming insects represent an environmental-friendly production and a regular supply of healthy and uniform specimens, it requires a costly regular technical guidance, timely financial assistance, and procurement of ingredients for artificial diets, not to mention that the acceptance of insect consumption has abated over the last 200 years due to the introduction of western foods, and NSA projects should consider what is culturally appropriate (Gahukar, 2020; Müller, 2019).

The role of fisheries in improving diets has been ignored when discussing sustainable food systems, despite the well-documented health benefits of fish to nutrition (Thilsted et al., 2016). Low-income countries tend to export high-value fish products and import low-value products for domestic consumption (Asche et al., 2015). Efforts should be put to improve nutrition of marginalized populations through fisheries because fish consumption can help support cognitive development, alleviate stunting, improve maternal and childhood health outcomes, strengthen the immune system, and reduce cardiovascular disease (Bennett et al., 2021; Thilsted et al., 2016). Michaux et al. (2019) reported that groups of Cambodian women and their children, exposed to nutrient intakes from both enhanced homestead food production and aquaculture for 22 months, showed lower prevalence of inadequate Vitamin A, riboflavin, and 10% bioavailable iron intakes, compared to control groups.

The fishery on freshwater fish stocks and its potential to contribute to a healthy diet has been neglected (Lynch et al., 2020). *Rastrineobola argentea* (Silver cyprinid), a small (max length 8.0 cm) fish traded in the East African region, is an example of an underutilized fishery (Ojwang et al., 2014). In Sub-Saharan Africa, small fish like Silver cyprinid represent an affordable option that is usually sundried and consumed whole (including head, bones, and viscera), which is a source rich in essential nutrients (e.g., vitamins A, D, and B12, calcium, iodine, selenium, iron and zinc), in contrast to large fish of which only fillets are eaten, limiting the potential nutrient content (Hasselberg et al., 2020; Nordhagen et al., 2020; Reksten et al., 2020).

Another type of food production intervention is biofortification: a process through which the density of vitamins and minerals (e.g., vitamin A, iron, iodine) in a crop is increased, and it can be accomplished through techniques such as plant breeding, agronomic and transgenic practices (Bouis and Saltzman, 2017). The impact of simultaneous fertilization of crops with selenium and zinc together with iodine has been studied (Cakmak et al., 2020), showing that foliar fertilization of wheat might be adequate to tackle the iodine deficiencies in populations with a moderate intake to high intake of wheat-based food. In another study conducted in Rwanda, it was shown that the consumption of iron-biofortified beans improved the iron status in women after 128 days (Haas et al., 2016). A couple of interventions in which orange sweet potato was biofortified with vitamin A reached 24,000 households in Uganda and Mozambique from 2006 to 2009 (Hotz et al., 2012a, 2012b), where adoption rates of orange sweet potato were greater than 60% above control communities, and vitamin A intakes among children and women was associated with improved vitamin status among children.

Urban and peri-urban agriculture includes the growing of plants and the raising of animals (e.g., crop production, small animal rearing, growing of cash crops or medicinal herbs and trees for production of fruits and fuelwood in agroforestry or tree-aquaculture systems) within and around the cities (FAO, 2017). McMullin et al. (2019) used a fruit tree portfolio approach; based on qualitative and quantitative data, context-specific recommendations were derived, promoting fruit species to address deficiencies of vitamin A and vitamin C. This can also be an example of an intervention that promotes the biodiversity for nutrition, because it focuses on native fruit species that could be highly beneficial for human's health but that are usually overlooked. A recent study analyzed what the farmers from the Global South must or can do in the context of urban-growth related changes along five dimensions: land, water, organic, fertilizer, labor, and food markets (Follmann et al., 2021).

3.3.2 Food handling, storage and processing

When moving along the value chain, agriculture is limited where food processing starts. Postharvest handling includes all the steps that a harvested crop has to go through from the producer to the market. The processing and handling of food can favor the seasonal food availability, because the shelf life of a food product is increased by preservation methods (FAO, 2017). Functional foods, for instance, are foodstuffs, including the industrially processed ones, that when regularly consumed within a diverse diet at efficacious levels have positive effects on health beyond basic nutrition, demonstrating specific health or medical benefits, including the prevention and treatment of disease (FAO, 2022a; Granato et al., 2017). Preserving the cellular viability, functions, and stability of starter cultures such as the lactic acid bacteria is a challenge in the development of functional foods, and trehalose has shown capability of maintaining of those probiotics under long term storage (Onwe et al., 2022).

The food fortification is a nutrition-specific intervention that should rapidly increase an individual's targeted population's exposure to the specific nutrient(s) (World Food Programme, 2012). The process of food fortification can be done during the processing phase (e.g., formulation) or at the point of use (e.g., household level). The success, hazards, and ethical implications depend on the deficiency it is trying to eradicate, and the circumstances related to its implementations

(Lawrence, 2013). There have been universal or mass fortification of basic staples or condiments: folic acid-fortified wheat flours, vitamin A-fortified cooking oil or iodized salt. The experiment performed by Cakmak et al. (2020) is an example of an intervention of food fortification, as it studied the effective retention of iodine in foods made of fortified wheat and rice flours. Insects are a good source of iron and zinc; thus they are considered in food fortification programs (van Huis, 2020). Consumption of insects in the western civilization is limited to the occasional snack, and it can even be rejected for being considered exotic (House, 2019). A good way to incorporate insects into people's eating habits is by adding them to other food products. Mealworms have been added to bread (5 to 10% substitution of wheat) without affecting the technological process and enhancing the protein content of the food product (Roncolini et al., 2019), demonstrating that insects can be in the formulation of foods that are already produced industrially at large scale. There are other instances in which insects have been added to other food products: mealworm larvae and silkworm pupae (Kim et al., 2016) or crickets (Keto et al., 2018) in sausages; crickets in energy, protein bars and pork pâté (Adámek et al., 2018; Smarzyński et al., 2019), and termites (Kinyuru et al., 2009) and crickets (Alemu et al., 2017, 2016; Pambo, 2018; Pambo et al., 2018) in buns, and pastas (Enwemiwe and Popoola, 2018; Lombardi et al., 2019).

3.3.3 Food trade and marketing

Trade for nutrition refers to the actions taken by nations to improve the availability and access of the food supply through fair trade agreements and policies and efforts to guarantee that such agreements and policies do not have a negative impact on the right to adequate food in other countries (FAO, 2017). The food industry has expanded in size and power of trans-national companies, especially food manufacturers producing certain types of ultra-processed foods (e.g., snacks, carbonated beverages, and other products high in salt, fats and sugars), and this is correlated to the increase in the prevalence of obesity and other non-communicable diseases (Garton et al., 2020). Therefore, governments should redesign policies to transform the food systems in such a way that there is a reduction in health and economic burden of non-communicable diseases. For instance, in India, after the liberalization of the edible oil sector, consumption of palm oil, mostly imported, increased from under 500 tones in 1994 to almost 10 million tonnes in 2016 (Cuevas et al., 2019). This represents both nutrition- and sustainability-related issues. Although affordable as an energy source, palm oil is high in saturated fatty acids compared with locally consumed oils in India, such as rapeseed/mustard seeds, and saturated fatty acids have been associated with increased risk of cardiovascular diseases (Downs et al., 2015; Mensink et al., 2003; Micha and Mozaffarian, 2010; Shankar and Hawkes, 2013). Regarding sustainability, the palm oil cultivation is linked to deforestation of tropical forests (Agus et al., 2013). Through policy documents and semi structured interviews with key experts and stakeholders in the edible oils sector, for example, Cuevas et al. (2019) has shown that the implementation of a sectoral agenda for sustainable nutrition is supported by the emergence of multisectoral approaches to the prevention of non-communicable diseases. The authors discussed the systematic efforts towards identifying synergistic approaches, from agricultural production to distribution of edible oils, as well as increased involvement of nutrition advocates of both nutrition and sustainability.

Food marketing and advertising practices is another type of intervention within this group. Food environment is the nexus between food systems and dietary consumption. The nutritional impact of an intervention depends on whether nutritious foods (or other items beneficial for nutrition) are available on local markets at affordable prices. It is important, therefore, to assess food availability before performing an intervention, especially in remote areas. Food marketing includes all activities, infrastructures and regulations involved in the physical sale of food (e.g., wholesaling, retailing, catering) as well as its promotion, such as discounts, display of products, branding and packaging, advertisement and use of media (FAO, 2017). Sibhatu and Qaim (2017) found that, even during the main harvest and post-harvest season in rural Ethiopia, purchased foods contributed more than one-third to total calorie consumption. Similarly, Koppmair et al. (2017) found that improving access to markets in Malawi was a more appropriate choice than increasing production diversity, meaning that strengthening rural markets should be a key strategy to improve food security and dietary quality in the small-farm sector. Cooper et al. (2021) emphasized the benefits from combining multiple nutrition-sensitive market interventions and stressed the need for policies that narrow the fruit and vegetable cold storage deficits that exist away from more lucrative markets in developing countries.

One of the biggest challenges is the current cost and affordability of healthy diets. The cost of food refers to what people have to pay to secure a specific diet, whereas affordability is the cost of the diet relative to income, and there is evidence of the link between cost and affordability of a diet and its quality, as well as their link to food security and nutrition outcomes (FAO et al., 2020). Therefore, interventions of food price policies for promoting healthy diets are needed. Food price policies refer to fiscal measures, such as taxes, subsidies and price ceilings. Gupta et al. (2021) quantified the divergence in the cost of current diets as compared to EAT Lancet recommendations in the subnational level in India, concluding that crop diversification, investments in rural infrastructure and well-functioning markets can move rural India forwards more nutrition-sensitive environments.

Food labeling is the last type of intervention within this food system function. The food label shows the information on the product (e.g., ingredients, health, safety, nutrition claims and nutrient content), thus it influences consumer's food-purchase decisions (Grunert et al., 2010; Hwang et al., 2016; Liu et al., 2015) and their willingness to pay (De Steur et al., 2017; Gregori et al., 2015; Mogendi et al., 2016; Ran et al., 2015). Since food labeling is a cost-effective marketing tool and can promote healthy food eating behaviors, it can benefit both actors and consumers. Sustainability-related labels should also be considered, since they can empower consumers. Asioli et al. (2020) classifies the sustainability-related food labels based on the problems they attempt to tackle: environmental, social or ethical. Environmental labels deal with information regarding the production that has considered the care for the environment, such as organic labeling, or information on the product's carbon and water footprints, whereas social and ethical labels offer information on other aspects, such as animal welfare and fair trade. Wesana et al. (2020) studied a nutrition-sensitive chain label that was perceived by consumers as more important than traditional nutrition labels, which should be taken into account by industrial and policy actors in the agri-food sector to innovate and regulate labeling schemes in the context of nutrition-sensitive value chains.

3.3.4 Consumer demand, food preparation and preferences

Nutrition education and behavior change communication (BCC) is the first type of intervention in this group. Interventions of nutrition education deal with certain attitudes and practices to improve diets. The success of any NSA intervention depends on consumer's demand for nutritious food, and this demand will trigger the upstream-chain actors to promote nutrient retention or addition and prevention of losses in food and nutrients (Hattersley, 2013; Hawkes and Ruel, 2012). Therefore, nutrition knowledge is a key element. For instance, farmers in Kenya who received both agricultural and nutrition training were more likely to adopt biofortified beans than farmers who received only agricultural training (Ogutu et al., 2020). In rural Ghana, diet and growth of young children improved through integrated support for agricultural production of nutrient-dense foods and poultry, combined with nutrition and health training (Marquis et al., 2018). According to Murimi et al. (2017), interventions of nutrition education with a duration of over 5 months, no more than 3 focused objectives, randomization, use of theories, and fidelity are more likely to succeed. The nutrition quality of a food product is heavily dependent on the preparation method. For instance, Wijesinha-Bettoni and Mouillé (2019) compared the nutrient content of potatoes based on how they were cooked (e.g., boiled, fried), or what ingredients were added (e.g., water or oil), etc. They observed, for example, that B vitamins and Vitamin C are lost when there is an excessive washing or when potatoes are boiled in a large amount of water that is discarded after cooking. Therefore, nutrition education should consider food preparation in BCC programs so that food preparation methods that result in healthier options are preferred among the population. Behrens et al. (2018) for instance, followed an approach to promote healthier lunch sides (e.g., fresh fruit and vegetable instead of canned products, or fresh potatoes instead of the fried potatoes high in sodium), which represents a promising paradigm for improving elementary cafeteria food offerings.

Income generation for nutrition is another type of intervention from this dimension. This one refers to the strategies to leverage the potential of agriculture and food systems to generate income, while optimizing the likelihood that the income is spent on buying nutritious foods and accessing nutrition-enhancing services. For instance, agricultural production and other food system activities offer opportunities for generating income through the sale of agricultural products or wage labor. Nordhagen et al. (2019b) found that the income generation from chicken sales was a significant motivator for members of a community in Senegal to continue with the livestock production. Ogutu et al. (2019) demonstrated that commercialization in Kenya contributes to higher incomes, which improves food security and dietary quality in terms of calorie, zinc and iron consumption by increasing the added purchased foods from the market. They remark, however, the importance of enhancing market access to make smallholder agriculture more sensitive to nutrition. Income generation is not a solution to eradicate all types of undernutrition. For instance, it did not contribute to increase vitamin A consumption in Kenya, because the generated income from commercialization was spent on purchased foods, and the consumption of certain own-produced vitamin A rich foods was reduced in more commercialized households (Ogutu et al., 2019).

Social protection is a key element in a nutrition-sensitive investment because it targets families at risk of malnutrition, reaching a large number of poor households which may be constrained in nutrition-related decisions; social protection includes the cash or in-kind transfers, initiatives that protect the vulnerable from risks and improve the social status and rights of the marginalized (FAO, 2017). According to Alderman (2016), social protection increases the household budget dedicated to food, and, consequently, it changes both quality and composition of diets. It was shown that a transfer accompanied by a BCC increased the share of mothers with knowledge of iron deficiency, maternal awareness of multiple-micronutrient powders as well as the likelihood that their children 6-59 months consumed either such powders or an iron supplement in the previous week, and the results were significantly higher than those of the groups that received a transfer only (Hoddinott et al., 2018).

The school food and nutrition approach is a set of activities benefiting the nutrition of school-aged children (e.g., provision of nutritious meals, nutrition education, school gardens, school environments that support nutrition and health) (FAO, 2017). These types of interventions are known for being effective to improve both nutrition and education outcomes for schoolchildren in low- and middle-income countries (Ministry of Education et al., 2016). School meal programs are usually implemented through direct food provision or through cash transfers to schools, and they can reduce the short-term hunger in schoolchildren, increasing their ability to focus and learn at school (Shalini et al., 2014; Shrestha et al., 2020).

Humanitarian food assistance occurs in times of crises or emergency (e.g., forced displacements, living in camps or informal settlements, and includes the provision and distribution of food, cash and vouches for food purchase, as well as non-medical nutritional interventions for the benefit of conflict-affected people (FAO, 2017). An increase in humanitarian food aid is associated with decreased incidence of civil conflicts in sampled populations, saving lives in recipient countries (Mary and Mishra, 2020). The United Nations World Food Programme (WFP) is the world's largest humanitarian organization fighting hunger worldwide, using assistance to help communities rebuild their lives and return to normality. In 2019, 97 million people from 88 countries were helped by the WFP, and delivering food in their complex environments requires an agile, adaptable, and aligned supply chain (Lee, 2004; World Food Programme, 2020). Demand in this case has been defined in terms of predetermined food baskets, per beneficiary type, but (Peters et al., 2021) defined it as nutritional requirements: three macronutrients and eight micronutrients (their methodology works for any number of nutrients). The authors showed a model that optimized the food basket to be delivered, the sourcing plan and the transfer modality of a long-term recovery operation for each month in a predefined time horizon.

3.3.5 Cross-cutting issues

The first type within this group of interventions is the nutrition-sensitive value chains. A food value chain is the full range of farms and firms and their consecutive coordinated value-adding activities which transform raw agricultural materials into food products. There is evidence, however, showing that the food systems do not necessarily deliver nutritious foods, even to those who have the resources to obtain them (Alston et al., 2016). Therefore, nutrition-sensitive value chains are essential. When value chain interventions are comprehensively planned, they could potentially be a cost-effective way to favor food systems towards healthier diets (Allen and de Brauw, 2018). For example, a micronutrient fortified yogurt (2.1. mg of EDTA iron, 2.25 mg of zinc, 24 µg of iodine and 120 µg of vitamin A) was used as a nutrition-based incentive in milk value chain interventions in northern Senegal (Bernard et al., 2019; Port et al., 2017). This intervention also fits in the category of food fortification.

Women's empowerment and gender equality is another intervention within the group of cross-cutting issues. Women usually care about household nutrition more than men; consequently, women are more concerned with making decisions that lead to diverse diets (Hoddinott and Haddad, 1995; Malapit et al., 2015). Nevertheless, women tend to be constrained when it comes to agricultural decision making (i.e., little or no control of property rights over land, livestock, agricultural machinery and implements). In the food and agriculture sector, gender equity refers to the equal participation of women and men as decision-makers in rural institutions and equal access to productive resources, assets, decent employment opportunities, income, goods, and services for agricultural development and markets (FAO, 2017). Therefore, women's empowerment programs, in the context of agriculture, are critical to improve the role of women in nutrition-sensitive farming (Rukmani et al., 2019). Empowering women in Burkina Faso was beneficial not only for women's lives but also for their children's nutrition (Heckert et al., 2019). Gupta et al. (2019) found that empowering women was associated with lower log odds of a poor iron status.

NSA interventions on prevention, reduction and management of food loss and waste are indispensable because a third of the annual food produced for human consumption (1.3 billion tons) is lost or wasted along the food supply chain due to several context-specific factors (e.g., gaps in capacity of the food supply chain actors, inadequate storage facilities and food packaging, lack of access to markets and consumer behavior) (FAO, 2017). Efforts to reduce food losses or wastes and nutrient losses represent a way to get sustainable and nutritionally adequate diets that may lead to improving the health status of vulnerable populations in low- and middle-income countries (Wesana et al., 2018).

There are biological, chemical and physical hazards that should be avoided when processing foods. Among these hazards, harmful pathogens (e.g., bacteria, viruses, parasites) natural toxins (e.g., neurotoxins from fungi) and chemicals are included. Food safety refers to the measures that are considered along the food supply chain to assure that food will not cause adverse effects on people's health when consumed as its intended use (FAO, 2017). Food quality, safety and hygiene interventions are important because child undernutrition has been linked to disease burdens such as diarrhea, respiratory infections, and environmental enteric disorder (Humphrey, 2009; Korpe and Petri, 2012; Mbuya and Humphrey, 2016). Most of water, sanitation and hygiene (WASH) interventions and strategies are focused on toilet construction and related hygiene and water measures, such as handwashing, because humans are bearers of common pathogens, but few nutrition programs have considered reducing exposure to animal feces (Curtis et al., 2000; Lanata et al., 1998; Mara et al., 2010; Michaux et al., 2019; Sharma et al., 2021b). This subject should receive more attention because animal-sourced fecal matter have been proven to be more widespread than human-sourced feces (Schriewer et al., 2015). While livestock ownership (e.g., poultry) can benefit child growth, overly close exposure to poultry can be a risk factor for undernutrition due to increased risk of infection (Headey and Hirvonen, 2016). Water, irrigation and drainage are investment projects that may reduce risk of waterborne and vector-borne disease by increasing access to clean water (FAO, 2016).

When referring to food processing, there are threats, such as the mycotoxin contamination. Besides lowering the food product quality, the mycotoxin contamination can affect the population by chronic toxicity, the main human health burdens that result in cancers, especially liver cancer (Ayelign and De Saeger, 2020). Therefore, measures, such as good manufacturing practices (GMP), HACCP, and others (Udomkun et al., 2017) should be implemented to reduce/prevent the risk of mycotoxins and other contaminants. Research and policies should be integrative and more sensitive to impacts on food safety and nutrition aspects to attain nutrition security and healthy lifestyles while ensuring sufficiency and sustainability of production of safe and affordable foods.

3.4 The importance of a multi-pathway approach

Enhancing the nutritional status can be achieved through different pathways. Figure 3.2 provides a concrete example of a multi-pathway approach: the diversification of agricultural products could be implemented to affect the outcome "on-farm availability, diversity and safety of food" by meeting dietary gaps through own production (as observed in Table 3.1); at the same time, a behavior change communication (BCC) program can be implemented to affect the outcome "nutrition knowledge and norms" by increasing the awareness of healthy diets (as seen in Table 3.1). In that case, both outcomes should be measured. There are different indicators to measure the "on-farm availability, diversity and safety of foods": the availability of specific foods on farm (Feed the Future, 2016); the Shannon index or the Simpson index (Leprêtre and Mouillot, 1999) to determine the diversity of foods produced on-farm; the functional diversity index (Remans et al., 2011); the proportion of staple crop production that is biofortified; implementation of good agricultural practices, or the grain loss; the Tool for the Agroecology Performance Evaluation (TAPE), which provides a diagnostic of agricultural performance across many dimensions to move beyond standard measures of productivity (e.g., yield/hectare), and can be useful when determining the diversified production (FAO, 2019). On the other hand, when the intervention promotes nutrition behaviors or messages, or when it is desired to understand the likelihood of consumption of specific foods or the overall dietary patterns for various population sub-groups, indicators should be used to measure the "nutrition knowledge and norms". There is a set of indicators for nutrition and food safety-related knowledge (Fautsch Macías and Glasauer, 2014), but they are project-specific, depending on the promoted knowledge.

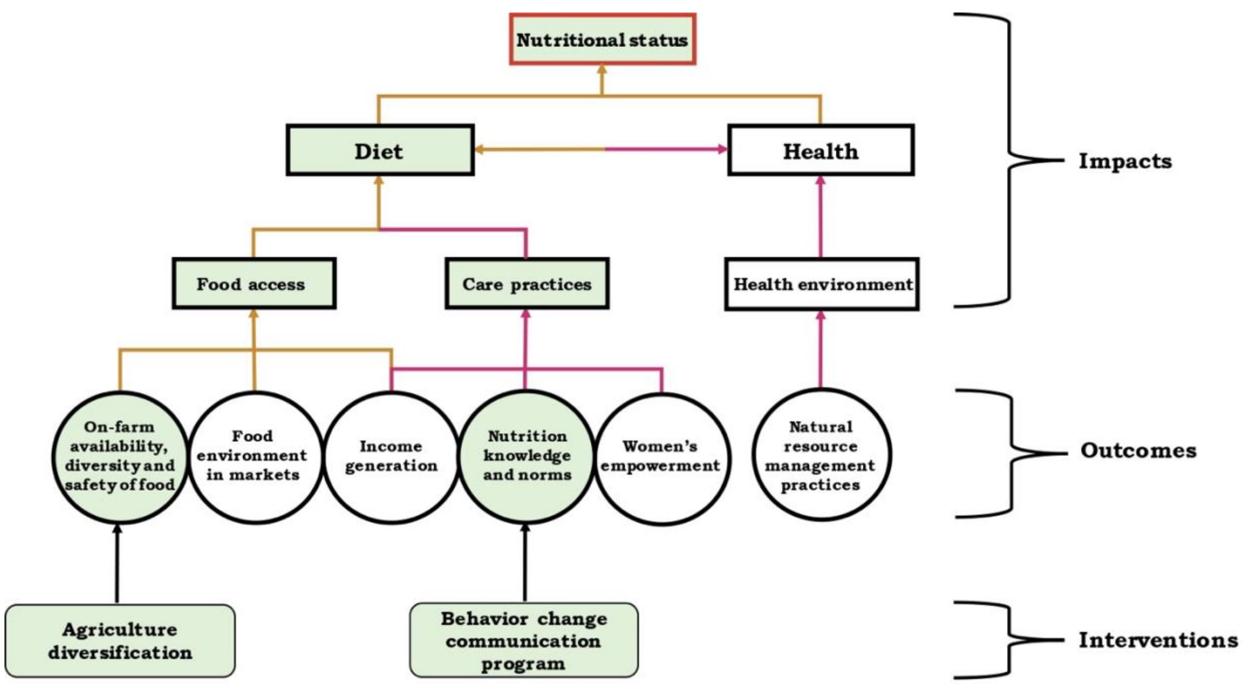

Figure 3.2 Conceptual framework showing the six outcome areas that are affected by agriculture, rural development and food systems, and how these can influence the nutritional status (FAO, 2017; Herforth and Ballard, 2016).

It will depend on the project managers and designers how far they want to reach towards the "nutritional status". For example, the objectives could be to improve the "food access" (e.g., seasonal variation and prices of food) through "on-farm availability, diversity and safety of foods" and the "care practices" through "nutrition knowledge and norms". To measure food insecurity and/or household access to and consumption of a variety of foods, there are indicators with their corresponding methodology, such as the food insecurity experience scale (FIES), which has been validated against the access dimension of food insecurity (FAO, 2022b); the food consumption score (FCS), which has been validated against the per capita calorie consumption within the households (WFP and VAM, 2008); the household dietary diversity score (HDDS) (Kennedy et al., 2012); or the household food insecurity access scale (HFIAS), which has to be adapted to be valid (Coates et al., 2007), among others. Food security has different dimensions: sufficiency, quality, acceptability, safety, and certainty/stability, and despite the many food security metrics, a suite of indicators that measure each dimension has not been established (Coates, 2013). Regarding the care practices, there are different ways of assessing them, such as breastfeeding indicators, which measure the frequency, duration or completeness of breastfeeding. Due to the fact that the minimum acceptable diet (MAD) combines standards of dietary diversity (a proxy for nutrient density) and feeding frequency (a proxy for energy density), it offers data on quality and quantity aspects of the diet of children with breastfeeding status; the minimum meal frequency (MMF), on the other hand, measures a proxy for energy intake from non-breastmilk foods among young children. Methodologies to use both MAD and MMF and other breastfeeding indicators are available (UNICEF, 2021).

An NSA project could aim at measuring the combined effect of "food access" and "care practices" on "diet quality". The impact indicators to assess diet quality are discussed in section 3.5.2 of this chapter. "Nutritional status" is the furthest one can attempt to reach, for which there are biochemical and anthropometric measures. It has to be considered that assessment of these indicators is expensive and invasive, since time for training the personnel, and blood samples or physical measures (i.e., weight and height) from the individuals are required to determine iron status (i.e., whether an individual's body is deficient or replete in iron) (WHO and CDC, 2007), anemia (i.e., hemoglobin level) (WHO, 2011), vitamin A status (i.e., whether and individual's body is deficient or replete in vitamin A) (WHO, 1996), stunting or wasting. Besides, when projects are intended to be short, there is no point in choosing these indicators, because no significant changes are observed when the interventions are not lasting enough (Dumas et al., 2018).

When following a multi-pathway approach, there are better chances of affecting more impact indicators. An intervention designed to only generate household income is expected to have an impact on food access or care practices. Wealth indices and poverty levels that measure the socioeconomic status should be used in this case as a proxy for income (Njuki et al., 2011). When appropriate, data on sales of agricultural products can also be collected; the value of incremental sales (collected at farm-level) can be useful (Feed the Future, 2016). Income alone, however, is unlikely to have an impact on diet quality, because the population will not necessarily be aware about the health benefits of consuming nutritious foods. It could happen the other way around, a BCC can be conducted, but if the population does not have the resources to obtain the foods promoted by the intervention, it is unlikely to observe an improvement in diet quality. For example, Schreinemachers et al. (2019) used school vegetable gardens to implement nutrition education on the nutritional awareness, knowledge, perceptions, and eating behavior of 8-14-year-old schoolchildren in Burkina Faso, finding a significant increase in knowledge of sustainable agriculture and knowledge of food and nutrition. However, the lack of resources did not allow the increase in other outcome indicators, including fruit and vegetable consumption. Besides, the poor infrastructure did not allow people to implement hygiene measures appropriately.

When planning an NSA project, the first step would be to study the context of the community: the underlying causes of malnutrition. At this stage, the potential beneficiaries have to be targeted (the most vulnerable ones), so equity can be achieved through participation, access to resources and decent employment. Then, the type(s) of NSA interventions can be identified to design suitable activities that address the causes of malnutrition or to achieve the explicit nutrition objectives. Once the theory of change and pathway(s) have been drawn, the proper outcome and impact indicators have to be selected, depending on several factors, such as budget limitations, sample population, duration of the project, etc. FAO (2016) offers a compendium of about 60 indicators categorized into the outcomes and impacts shown in Figure 3.2. There are, however, many more, and it is difficult to keep track of what each one reflects and does not reflect. At this point, it is clear that the design of NSA projects can become a difficult task. Therefore, there is a need to create algorithms that facilitates the task.

3.5 Metrics, instruments, and indicators to assess diet quality

3.5.1 Dietary assessment tools

Table 3.2 compares the dietary assessment instruments in terms of study design, scope of interest and other features. Food records (FR), food frequency questionnaires (FFQ), and 24-h recalls (24HR) are common tools to assess the diet and/or energy intake of individuals, and these instruments have provided useful data for the development of public health policy, the identification and understanding of the consumption of different food groups and their relationship with diseases, as well as the association between eating patterns and weight loss (Johnson, 2002; Subar et al., 2015).

3.5.1.1 24-h dietary recall

The 24-h dietary recall (24HR) is a structured interview that aims to get data on all foods and beverages (and possibly dietary supplements) consumed on a given day (usually from midnight to midnight the previous day). The interview gathers detailed information by asking, when appropriate, more specific information than first reported (e.g., a respondent reporting chicken salad for dinner would be asked about the preparation method to provide information on ingredients). The 24HR also collects data on time of day, source of food and portion size of foods and beverages. To avoid subjectivity from the respondent, food models, pictures and other visual aids are used. The 24HR is usually administered by a trained interviewer, but it can be self-administered with tools that have been developed (Foster et al., 2019; Lafrenière et al., 2018; Vereecken et al., 2008). Depending on the design of the interview, the 24HR takes from 20 to 30 minutes to complete, and a single intake is not enough to describe the usual diet (Johnson, 2002).

Table 3.2 Comparison of some characteristics of the dietary assessment tools: 24-hour recall (24HR), food record (FR), food frequency questionnaire (FFQ), and screeners (SCR).

		24HR	**FR**	**FFQ**	**SCR**
Study design	Cross-sectional	X	X	X	X
	Retrospective			X	X
	Prospective	X	X	X	X
	Intervention	X		X	X

Scope of interest	Total diet	X	X	X	
	One or few components			X	X
Captures contextual details regarding food preparation, timing of meals, location of meals, etc.	Yes	X	X		
	No			X	X
Time frame of interest	Short term	X	X		
	Long term			X	X
Can be used to query diet in distant past	Yes			X	X
	No	X	X		
Allows cross-cultural comparisons	Yes	X	X		
	No			X	X
Major type of measurement error	Random	X	X		
	Systematic			X	X
Potential for reactivity	High		X		
	Low	X		X	X
Time required to complete	<15 minutes				X
	>20 minutes	X	X	X	
Memory requirements	Specific	X			
	Generic			X	X
	Does not rely on memory		X		
Cognitive difficulty	High			X	X
	Low	X	X		

3.5.1.2 Food record

The food record (FR), a.k.a food diary, is a self-reported account of foods and beverages consumed by a respondent over one or more days with no limits on the number of included items. Seven-day records used to be the standard for validating other methods (Johnson, 2002). Recording and some oral or written instructions can be delivered so that the respondents offer detailed information on what they consume: brand names, preparation methods, etc. As with the 24HR, visual aids may help estimate portion sizes, but weight scales and volume measures (e.g., measuring spoons and cups, bowls, drinking glasses) are also provided. At least 15 minutes are required for the food record to be complete each day, and it has been observed that having an interviewer review the completed record with the respondent improves the quality of the report (Cantwell et al., 2006). One of the limitations is that FRs require literate, motivated subjects and place a high burden on the respondents. Besides, hand-written food records may be inexpensive to collect but expensive to code. FRs do not rely on memory, but the quality of the data declines with increased number of days recorded and FRs may cause reactivity (e.g., respondents decrease the complexity of their diet by substituting foods that are easier to record). Therefore, FRs are not recommended to evaluate the ensuing changes from an intervention (Gersovitz et al., 1978; Rebro et al., 1998).

3.5.1.3 Food frequency questionnaire

The food frequency questionnaire (FFQ) aims to obtain frequency and, in some cases, information on portion size of foods and beverages consumed over a specified period, typically the past month or year. FFQ consists of a finite list of foods and beverages and the respondent is asked if they eat them and if so, how often and how much they eat them. The FFQ must be culture-specific; lists of foods have been developed for determining the diversity of diets within different groups (e.g., Hawaiians, Japanese, Chinese, Filipinos, whites) (Hankin et al., 1991). FFQ can also ask about the frequency of intake and dosages of consumed dietary supplements. This instrument is usually self-administered, but a trained interviewer may help when literacy is low. Completing a questionnaire that measures the total dietary intake takes from 30 to 60 minutes. Some of the limitations of the FFQ include the systematic error, the lack of detailed data on food preparation, specific food and beverages consumed, and brands, and contextual information of intake (e.g., which foods and beverages are consumed at the same meal), as well as the fact that the performance of a particular FFQ in a population may not reflect its performance in a different population.

3.5.1.4 Screeners

Screeners (SCR) can be simplified targeted FFQ that focus on specific behaviors other than the frequency of consuming specific foods (Pérez Rodrigo, 2015). Completing an SCR can take less than 15 minutes. Due to its systematic error, just as in the case of the FFQ, SCR is not recommended to describe a population's intake in cross-sectional studies. The systematic error from both instruments can be mitigated through statistical modeling, using a less biased dietary assessment method as a reference instrument. Because of how similar SCR and FFQ in their design, they share other limitations (e.g., lack of detailed information on food preparation).

3.5.1.5 New technologies/methodologies

Archundia Herrera and Chan (2018) found about monitors and sensors (e.g., automated wrist motion tracking, intelligent food-intake monitor), camera-scan-sensor-based technologies that usually require a smartphone (e.g., remote food photography method, real-time food recognition system), and one mathematical method, all of which are innovative dietary assessment tools that can capture more accurately than the conventional methods, such as 24HR or FFQ and other paper-based records or recalls. Mahal et al. (2023) developed a smartphone app that not only takes data on food consumption, but also calculates different food quality and food access indicators. However, these new methodologies should be used with care because they are still being refined.

3.5.2 Types of indicators that measure diet quality on NSA interventions

When the intervention affects "on-farm availability", "food environment in markets", "income", "women's empowerment" and/or "nutrition knowledge", with hypothesized impact on diet through "food access" and/or "care practices", diet quality should be assessed. The use of quantitative 24HR can be used to determine other indicators, such as quantitative nutrient intakes, the consumption of 400 g fruits and vegetables per day (this can also be obtained from FRs), proportion of the diet consisting of processed/ultra-processed foods. Depending on the chosen indicator(s), 24HR or FFQ can be used to obtain data on Vitamin A-rich and iron-rich food consumption, and consumption of specific target foods (FAO, 2016). However, only a few indicators have been validated for population level use in resource-poor settings: the minimum dietary diversity for women of reproductive age (MDD-W), and the infant and young child feeding practices-minimum dietary diversity (IYCF-MDD), which reflects nutrient adequacy, and dietary diversity practices in the case of YCFP-MDD (Verger et al., 2019). These indicators can be obtained from 24HR, and portion sizes are not necessarily required.

3.5.2.1 Minimum dietary diversity for women of reproductive age (MDD-W)

Due to physiological demands during pregnancy and lactation, women are susceptible to suffer from undernutrition (Black et al., 2013). Therefore, when an NSA intervention aims at affecting diet quality and selects women among the beneficiaries, it is recommended to use the MDD-W, which is a proxy for micronutrient adequacy consisting of ten food groups (FAO, 2021):

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 or ingredients weighing equal to or more than 15 g from each food group. The women in reproductive age who consume at least five MDD-W food groups, in a 24 h period, are considered to meet their physiological needs and nutrition requirements with diet diversity.

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

The first thousand days of an infant are critical for their physical and cognitive development (Cusick and Georgieff, 2016). Therefore, the infant and young child feeding (IYCF) practices are vital. Apart from breast feeding, infants should start consuming complementary foods once they are six months old, and the minimum dietary diversity can be measured using the IYCF-MDD indicator, which has eight food groups (UNICEF, 2021): 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 practices for better growth and development of children can be achieved by feeding them with at least 5 food groups in a 24 h period.

3.5.2.3 Global diet quality score (GDQS)

Recently, Bromage et al. (2021) developed the global diet quality score (GDQS), a food-based metric consisting of 25 food groups classified as healthy, unhealthy, or unhealthy when consumed in excessive amounts. GDQS represents the first food-based metric of diet to be comprehensively validated against health outcomes, and has been established to perform well compared with MDD-W in capturing nutrient adequacy, and even anthropometric and biochemical indicators of undernutrition. Calculating the GDQS using an FFQ or repeated 24HRs or FR in at least a subgroup is suggested to accurately estimate the distribution of usual intakes or associations between the GDQS with health outcomes at the individual level (Bromage et al., 2021).

3.6 Multi-criteria decision analysis and its relevance in agriculture-related issues

Multi-criteria decision analysis (MCDA) involves different methods that support the decision maker in their unique and personal decision process, providing stepping-stones and techniques for finding a solution (Figure 3.3) (Ishizaka and Nemery, 2013). MCDA methods place the decision maker at the center of the process, incorporating subjective information, which is also known as preference information.

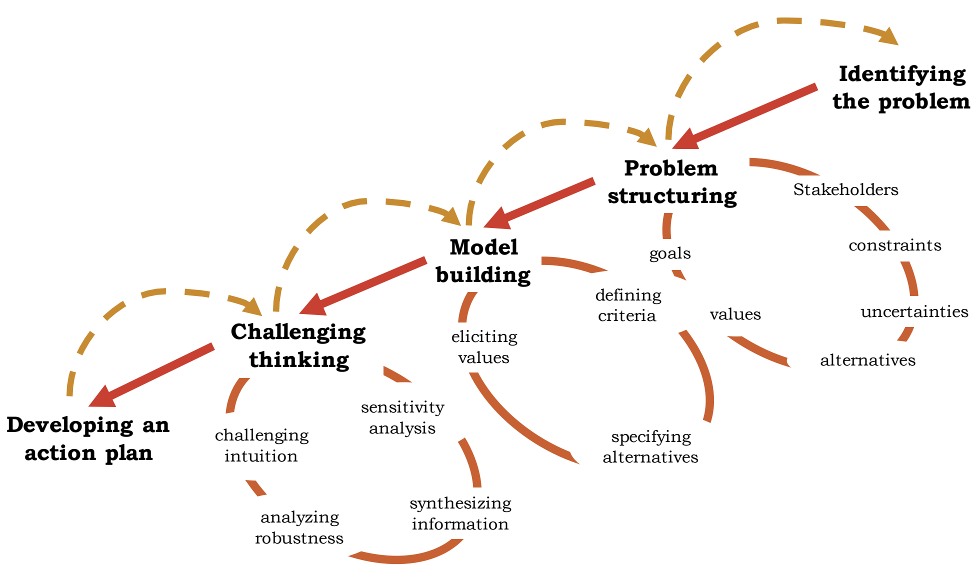

Figure 3.3 The process of multi-criteria decision analysis (MCDA) as suggested by Belton and Stewart (2002).

MCDA encompasses mathematics, management, informatics, psychology, social science and economics (Ishizaka and Nemery, 2013). According to Ogrodnik (2019), MCDA can either make use of aggregation methods (i.e., analytic hierarchy process (AHP) and multi-attribute utility theory (MAUT)), surpassing methods (i.e., elimination and choice expressing the reality (ELECTRE) and preference organization method ranking for enrichment evaluations (PROMETHEE)), geometric distance methods (i.e., the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and multi criteria optimization and compromise solution (VIKOR)), interactive methods (e.g., RUBIS) or verbal decision analysis methods (e.g., ZAPROS).

Different types of problems can be solved using MCDA (Table 2.3): choice (e.g., a manager selecting the most suitable area for peri-urban agriculture), sorting (e.g., classifying NSA projects into performance categories such as "outperforming", "average-performing" and "weak-performing"), or ranking problems (e.g., ranking brands of a food product according to several criteria) (Ishizaka and Nemery, 2013). Each MCDA method has its own limitations, particularities, hypotheses, premises and perspectives, and it is subsequently not possible to determine whether one method makes more sense than another in a specific problem situation. There are, however, some ways of choosing MCDA methods to solve specific problems. One way is to look at the data and parameters of the method and the modelling effort, as well as looking at the outcomes and their granularity as supported by Guitouni et al. (1999). Table 2.4 shows the outcomes as well as the required inputs for the MCDA ranking or choice methods.

3.6.1 Relevance of MCDA in agriculture-related issues

Regarding agriculture-related topics, MCDA has been used to resolve complex problems such as determining the soil erosion and degradation (Grau et al., 2010), measuring the sustainability level of agricultural systems (Talukder et al., 2018, 2016), interpretation of stakeholders' multidimensional perceptions on policy implementation gaps regarding small-scale seaweed aquaculture (Henríquez-Antipa and Cárcamo, 2019), tillage practices to mitigate negative environmental impact to soils (Król et al., 2018), finding the suitable zones of peri-urban agriculture (Majumdar, 2020), and the development of strategically located land index to identify areas suitable for agricultural land reform or for cultivation priority planning of different crops (Musakwa, 2018; Seyedmohammadi et al., 2018).

Ardakini et al. (Ardakani et al., 2017) applied the TOPSIS method to build a dynamic quantitative national-level food and nutrition security index to be used as a benchmark for the dimensions of food and nutrition security and prioritize the vulnerabilities of food system in the delivery of food and nutrition security in Iran. As discussed above, there are many things to consider (e.g., context of the community, goals, budget and other resources at the disposal of the project manager and their team, most suitable metrics and indicators) when designing an NSA intervention, and it can become a difficult task. MCDA is a powerful tool with the potential to help design NSA projects in an easier way. TOPSIS, specifically, has the advantage that the amount of effort needed during input is relatively low, and it offers a complete ranking with closeness scores.

3.6.2 Potential of MCDA to design NSA projects

As mentioned above, there are several types of NSA interventions grouped into 4 food system functions and 1 cross-cutting issues. The decision on which one(s) to choose depends mostly on the context of the community (e.g., the agricultural practices that they perform, the health or the educational status of different segments of the population, what is considered culturally appropriate). Once the population and its surroundings have been studied, a pathway can be defined to achieve the set nutrition objectives. Based on the pathway, certain indicators have to be selected to determine the success (or failure) at each step. As previously discussed, the significant number of indicators makes it difficult to track what each one reflects, which may lead to misinterpretations (e.g., an indicator that measures food access can be wrongly chosen to determine diet quality). Besides, several metrics and technological tools are available to the required data for each indicator. Surprisingly, MCDA has not been used to design NSA interventions. MCDA consists of three stages: 1) structuring the problem, 2) model building and use, and 3) development of action plans.

3.6.2.1 Structuring the problem

This phase consists of rationalizing an issue, identifying key concerns, goals, stakeholders, actions, uncertainties, etc. In other words, problem structuring is the identification of the factors and issues that should be discussed and analyzed (Belton and Stewart, 2002). The starting point in any pathway, as seen in Figure 2, is the type of NSA intervention. The problem is how to choose a type of NSA intervention based on the context of the targeted population, the sectors with which there might be collaborations, to avoid redundancy in efforts, etcetera. This phase is basically thinking of all the possible alternatives as well as the criteria that should be considered.

3.6.2.2 Model building and use

As explained by Belton and Stewart (2002), this phase should be a dynamic process, informed by and informing the process of problem structuring, and interacting the process of evaluation. The key elements of the model framework in this case are: a) alternatives, such as the types of NSA interventions (e.g., biofortification, women's empowerment, nutrition education and BCC), b) model of values, such as criteria, objective, and goals (e.g., duration of the project, explicit nutrition objectives, health context or education status of different segments of the population, outcome and impact indicators), c) stakeholders, and d) uncertainties. As observed above, MCDA methods require a decision matrix that should be built with the alternatives and the criteria. The model building and use may involve iteration, search for new alternatives and criteria, discarding, reinstating, and redefining of old ones, and further extensive discussion among the participants. The ensuing algorithm that is planned should provide a ranked list of the NSA interventions, from the most relevant to the least relevant, based on the data that the user inputs in the criteria.

3.6.2.3 Development of action plans

MCDA is concerned not only with the analysis, but also with the implementation of results, which means translating the analysis into specific plans of action. In this case, the developed algorithm should provide information not only on how to design the selected NSA intervention(s), but also on the potential pathways, what indicators should be used and how to collect properly the data to assess those indicators (i.e., what metrics to use and how to use them), and how to interpret them. Among the different MCDA methods, TOPSIS has the advantage that the amount of effort needed during input is relatively low, and it offers a complete ranking with closeness scores, which is expected from the algorithm to design NSA projects.

3.7 Conclusion

Despite the efforts to reduce malnutrition, there are still communities around the world that are susceptible to micronutrient deficiencies and other forms of malnutrition. NSA is an approach that has been theorized to address the causes of malnutrition, and different types of interventions have been fitted into four food system functions and one cross-cutting issues. Multi-pathway approaches are preferred when aiming at improving the nutritional status, but there are still gaps when it comes to designing NSA projects (e.g., not necessarily the most suitable types of NSA interventions are selected, the outcomes or impacts are not measured in the complete defined pathway, or the metrics and indicators are not properly selected due to the difficulty of keeping track of what each one reflects). MCDA methods have been employed to solve complex agriculture-related issues, and future research is required to develop an approach that helps optimize the design of NSA interventions using an MCDA method, such as TOPSIS, which could offer a complete ranking of the types of NSA interventions with closeness scores, based on objective criteria. Besides, the developed algorithm could help choose the suitable indicators to measure the outcomes and impacts in a defined pathway, and it could provide the know-how on collecting data using the right metrics. This would be highly beneficial, since it could help stakeholders build the empirical evidence required to demonstrate the impact within the time frames and sample sizes of the NSA projects.

CONNECTING TEXT

The types of interventions, metrics and indicators for NSA projects have been explored thoroughly. It is clear that, to satisfy both the energy and the nutrients requirements of a community, it may be necessary not only to produce nutritious crops, but also to include non-dietary pathways, such as women's empowerment or behavior change communication programs. It is also clear that appropriate metrics and indicators should be used to measure the impact at each step of the pathway to determine the success or failure of an intervention.

Chapter IV focuses on the third objective of this thesis (i.e., to perform a meta-analysis of current NSA projects to understand their core characteristics (e.g., target population, sample size, pathways, metrics, indicators), and to validate the adopted methodologies). Thus, current studies that have performed NSA projects were dissected not only to validate their methodology, but also to understand the pathways that they followed, as well as the metrics and indicators that were used to measure their impact. By doing so, we get a better understanding of how types of NSA interventions and indicators can be associated. Chapter IV has been submitted to Nutrition Research, co-authored by Dr. Michael Ngadi, Dr. Christopher Kucha, and Dr. Ebenezer Kwofie.

IV. NUTRITION-SENSITIVE AGRICULTURE INTERVENTIONS TEND TO OPT FOR MULTI-PATHWAY APPROACHES: A SYSTEMATIC REVIEW

4.1 Abstract

Nutrition-sensitive agriculture (NSA) aims to produce, sustainably, a variety of affordable, nutritious, culturally appropriate and safe foods. NSA interventions have been developed to improve the nutritional status through different pathways (e.g., increasing crops' diversity to improve food access or diet quality). NSA projects are specific-context and they have shown to be inconsistent in terms of impact. The systematic literature search was performed on Web of Science, PubMed and JSTOR from 2010 to February 2022. Current projects were designed mostly within the food production dimension (e.g., diversification and sustainable intensification of agricultural production). To assess the impact of NSA interventions, direct dietary quality parameters, such as the individual and household diet diversity indicators (e.g., Minimum Dietary Diversity for women of reproductive age (MDD-W)), were the most common selections, as well as indicators that measure the nutritional status from different perspectives (i.e., biochemical, such as iron status, and anthropometric, such as stunting). Our findings suggest that an NSA intervention should be lasting enough in order to perceive any significant changes in biochemical or anthropometric measures. The methodology validity is essential when formulating policy and, therefore, to improve the enabling environment. About 65% of the analyzed interventions worked with samples that were smaller than the necessary to validate power, and this was attributed to budget limitations. Future work should focus on the duration of certain type NSA interventions to notice significant changes in the outcomes that are to be measured. Our results show relevant insight for future project designers and implementors.

Key words: Nutrition-sensitive agriculture; food systems; enabling environment; diet quality indicators; anthropometric measures; biochemical measures.

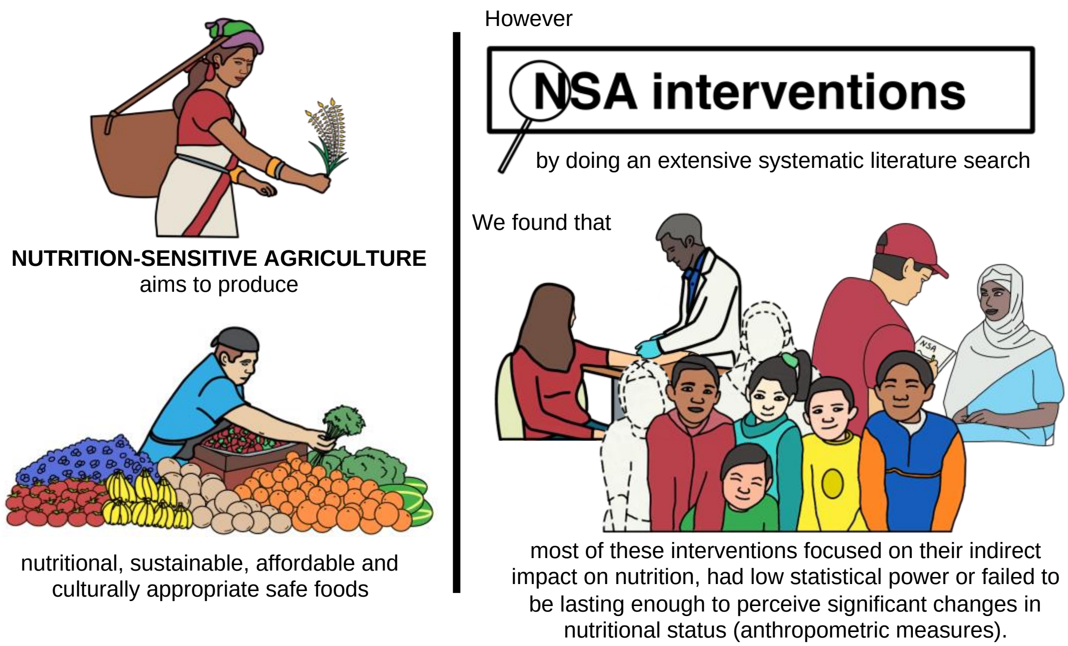

Figure 4.0 Graphical abstract.

4.2 Highlights

- Food production and consumer-focused interventions were the most abundant ones
- Women's empowerment has become relevant as an indirect nutrition approach
- Diet quality, food access, and nutritional status indicators were common selections
- A contextual framework should be considered when designing interventions
- Two thirds of the selected studies worked with samples that did not validate power

4.3 Introduction

Since agriculture is the main occupation of 80% of poor rural populations (Ruel and Alderman, 2013), it has been suggested as a tool to fight against undernutrition. Nutrition-sensitive agriculture (NSA) has been described as an approach produces, in a sustainable manner, a variety of affordable, nutritious, culturally appropriate and safe foods in sufficient quantity and quality to meet the dietary requirements of populations (FAO, 2017). Over the last decade, the contribution of agriculture to nutrition through NSA interventions has been a primary focus of research. The research agenda has been to understand the forms through which nutrition can be improved and measured in interventions. Nutrition challenges are not only addressed from a nutrition perspective; health components from different sectors (e.g., health, social protection, women's empowerment) should also be considered. Therefore, NSA interventions have become more and more complex; some of them consider multisectoral aspects and sometimes they even operate in a multi-country mode (Nordhagen et al., 2019a).

It is fair to say that NSA interventions rely on mitigating the underlying causes of nutrition (Ruel and Alderman, 2013). FAO (2017) explains in detail the different types of NSA interventions (e.g., nutrition-sensitive livestock and fisheries, diversification of agricultural production, food fortification, income-generation activities, nutrition education and behavior change communication).

Despite the efforts to reduce food and nutrition insecurity, NSA interventions have shown inability to small variations in nutrition outcomes due to the deficiencies in the study design methods (Masset et al., 2011; Webb and Kennedy, 2014). Interventions have also been limited when it comes to measuring the full pathway of change (Hawkes et al., 2012; Turner et al., 2013). Herforth and Ballard (2016) highlight the three critical pathways through which agriculture can affect nutrition outcomes: food access, care practices, and health environment. There are different pathways towards the nutritional status in a food system (e.g., increased production of biofortified crops, combined with nutrition education and a program of change behavior communication, might have an impact on both food access and care practices to improve the dietary quality and, eventually, the nutritional status of a population). The selection of indicators to measure the impact of an NSA intervention will depend on the pathways that the program follows, as well as the enabling environment of the communities. Several categories comprise the enabling environment (i.e., government/institutions, policies, capacity, infrastructure/interactions, and research/knowledge).

The objective of this work was to evaluate recently published NSA studies focused on measuring/tracking the nutritional improvement from agriculture projects. An analysis of the nutrition impact pathway and dimensions and the associated indicators across a range of NSA projects was performed. Additionally, the methodological validity and the enabling environment for implementation were reviewed. Finally, an indicator-based discussion of the nutrition outcomes is presented. This work offers the current trends in NSA projects and it will be useful for researchers and implementers who plan to design interventions.

4.4 Methodology

A systematic review was conducted to study the core characteristics (i.e., dimensions and indicators) of NSA projects that have been published in peer-reviewed articles from 2010 to February 2022 (Figure 4.1). The performance and impact of such NSA projects were critically analyzed. The systematic review was carried out following a five steps process: 1) literature search, 2) data collection and screening, 3) classification of studies into their corresponding dimensions and types of indicators, 4) methodological validity and enabling environment assessment, and 5) outcome analysis, which are explained in the following sections.

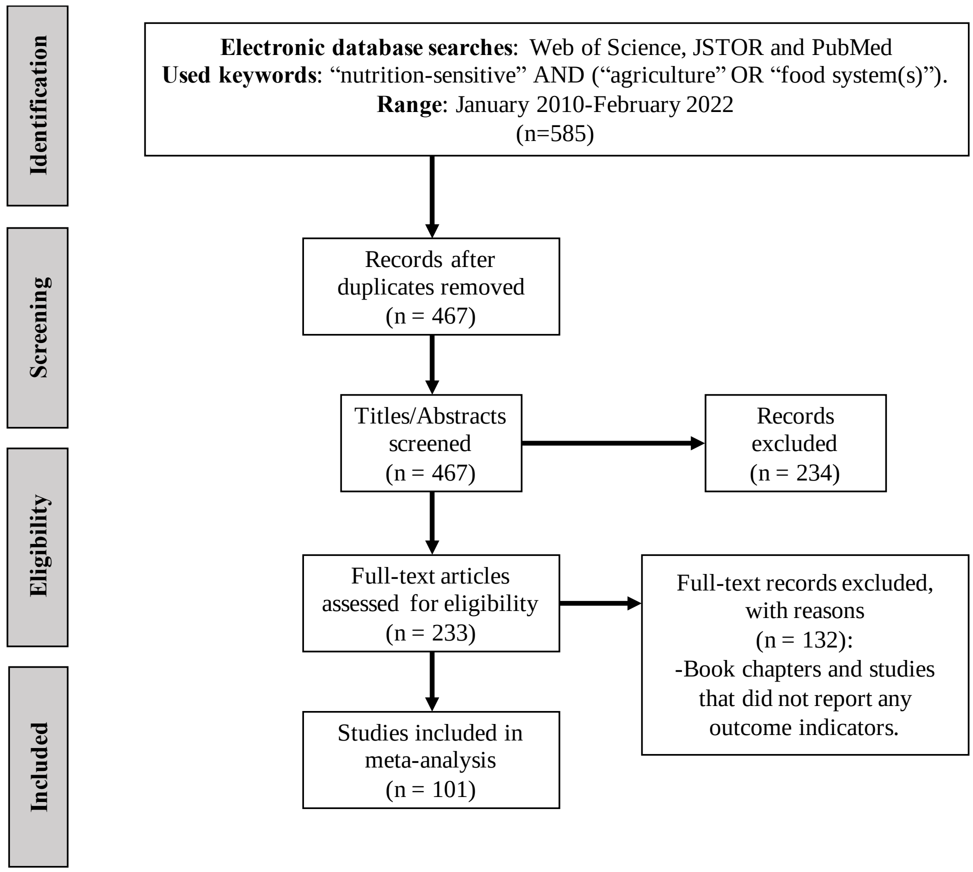

Figure 4.1 Systematic review flow diagram. The PRISMA flow diagram for the systematic review detailing the database searches, the number of abstracts screened and the full texts retreived.

4.4.1 Literature research

A search of peer-reviewed documents using two multidisciplinary databases: Web of Science, PubMed and JSTOR was conducted. The used keywords were: "nutrition-sensitive" AND ("agriculture" OR "food system(s)") found in the title or abstract of the document. The search was limited to works published from 2010 to date and resulted in 585 documents found.

4.4.2 Data collection and screening

The search was followed by a screening process. After removing the duplicates, 467 documents were taken into account. The remaining articles were discriminated based on their content. All the reviews were discarded. Book chapters and abstracts from conferences and studies that did not report any outcome indicators were also excluded. In the end, 101 articles were selected for the analyses. We decided to include even those projects in which they did not have a control group or did not worry about adjusting for selection bias. The methodology, however, was graded for both internal and external validity, as explained in the fourth step (*section 4.4.4*).

4.4.3 Dimensions and indicators classification

The classification of the selected interventions was done using FAO's suggested common indicators for nutrition-sensitive agriculture and food systems interventions (FAO, 2017). We used the four key functions of the food system and cross-cutting issues through which agriculture and food systems can be made nutrition-sensitive. These key functions referred to as dimensions take into account the primary entry point for nutrition improvement. As seen in Table 4.1, each dimension has different types of interventions. The different indicators to assess the impact of NSA interventions presented in the FAO compendium (FAO, 2016) was used to classify the selected the 101 selected interventions into the different dimensions. All the indicators used in each project were identified and reported.

Table 4.1 The types of nutrition-sensitive agriculture (NSA) interventions that correspond to each food system dimension.

Dimension	**Type of intervention**
Food production	Diversification and sustainable intensification of agricultural production
	Nutrition-sensitive livestock and fisheries
	Biodiversity for food and nutrition
	Biofortification
	Urban and peri-urban agriculture
Food handling, storage and processing	Nutrition-sensitive postharvest handling, storage and processing
	Food fortification
Food trade and marketing	Trade for nutrition
	Food marketing and advertising practices
	Food price policies for promoting healthy diets
	Food labelling
Consumer demand, food preparation and preferences	Nutrition education and behavior change communication
	Income generation for nutrition
	Nutrition-sensitive social protection
	School food and nutrition
	Nutrition-sensitive humanitarian food assistance
Cross-cutting issues	Nutrition-sensitive value chains
	Women's empowerment and gender equality
	Food loss and waste: prevention, reduction and management
	Food quality, safety and hygiene

4.4.4 Methodological validity and enabling environment assessment

As suggested by Masset et al. (2011), we carried out an analysis for both internal and external validity of each article. The internal validity was defined as the ability of the study to establish causality. Two criteria, as shown in Table 4.2, were considered: the use of a valid control group (counterfactual analysis) and the use of a sample size large enough to detect a difference in the outcome(s) of interest (power).

Table 4.2 Criteria for the internal and external validation of the methodologies in the different studies.

	Criteria	High score	Medium score	Low score
Internal validity	Counterfactual analysis	Randomized experiment Sound matching technique Difference in difference analysis Credible selection correction	RCT, matching or double difference analysis poorly performed Selection correction not credible	Comparison of participants to unmatched non-participants Before-after comparisons No control group
	Power	Power calculations over variables of interest	Week power calculations	No power calculations Sample from a specific area or population
External validity	Programme theory	Intermediate outcomes estimated	Intermediate outcomes considered but not analysed	No intermediate outcomes considered
	Heterogeneity	Heterogeneity of impact analysed	Heterogeneity considered but not analysed	No heterogeneity considered

For external validity, two factors were considered: the program theory (the use of intermediate outcomes to assess the impact of the intervention in the full pathway), and heterogeneity (the level of analysis of the impact of a project). For instance, some studies focus only on the average intervention effect on the population, while others report the impact depending on the socioeconomic conditions of the households.

There are five critical categories of enabling environment: government/institutions, policy, capacity, infrastructure/interactions, and research/knowledge. Based on the context of the populations of the selected studies, the enabling environments were graded as: "not at all", "not really", "to some extent", or "very much".

4.4.5 Outcome analysis

A critical analysis of the outcomes was carried out. Firstly, most used indicators were identified. Then, an analysis of how those indicators associated with the intervention dimensions was performed. A subsequent analysis of how indicators intertwined in different studies was conducted. Lastly, we discussed the nutritional pathways of the studies that selected the most common indicators, as well as their most significant findings and suggestions.

4.5 Results

4.5.1 Nutrition pathways and nutrition-sensitive agriculture dimensions

The analysis of the pathway through which was accessed is shown in Figure 4.2. The results reflect the dominance of food production interventions (66.3%) and consumer-focused interventions (48.5%). It reveals that interventions are usually not designed around one dimension but targets multidimensional impacts. Analysis of individual projects also reveals that the two main dimensions are usually linked with other cross-cutting interventions (31.7%), such as women's empowerment or nutrition-sensitive value chains.

Overall, Figure 4.2 seems to suggest a weak link between nutrition improvement and interventions on food trade and marketing, and post-harvest handling, storage, and processing. Although post-harvest losses have been recognized as major threat access to food (a key pathway to nutrition), there are relatively few nutrition-focused projects that make it their focus. Similarly, interventions of food trade and marketing are not oriented towards nutrition, which could be an opportunity to redesign upcoming interventions to capture nutrition improvements as part of the expected outcomes. Since the food production remains the primary food system failure (Béné et al., 2019), it seems obvious that interventions tend to be oriented towards improving that dimension. With a focus on closing the yield gap and ensuring that enough calories are produced to feed that anticipated 9 billion people in the coming decade, food production continues to lead the pathway to nutrition agenda.

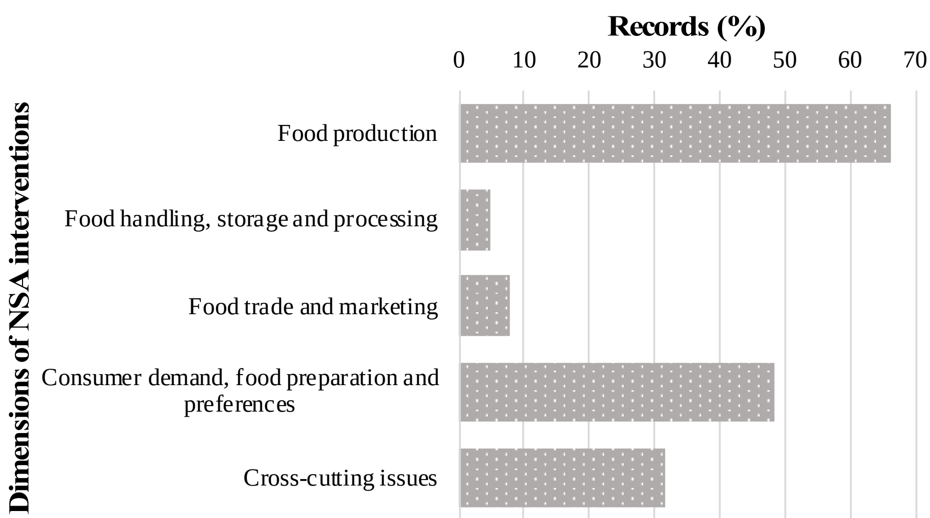

Figure 4.2 Dimensions of the nutrition-sensitive agriculture (NSA) interventions.

Figure 4.3A shows that 39.6% of the food production interventions are focused on diversification and sustainable intensification of agricultural production. The results also show less focus on biofortification interventions, which have typically not been included in some NSA reviews due to their lack of agricultural components (Hawkes et al., 2012). Nutrition-sensitive livestock and fisheries interventions represent 27.7% of the selected interventions. This seems to reflect the argument made for the contribution of fish and livestock to food and nutrition security above their intrinsic nutrient content due to the facilitation of nutrient uptake (Belton and Thilsted, 2014).

Nutrition education and behavior change communication have been reported to be an important path to enhance nutrition knowledge among intervention participants and, more importantly, to enhance program uptake and increase positive nutrition outcomes (Alive and Thrive, 2018; Kadiyala et al., 2016; Warren et al., 2020). Analysis of the individual interventions reveals that nutrition education is the most used subdimension, representing 39.6% of the selected studies (Figure 4.3B). However, nutrition education is usually included as a subcomponent of many interventions focused on other dimensions. As mentioned by Murimi et al. (2017), interventions of nutrition education that have a duration of over 5 months, no more than 3 focused objectives, randomization, use of theories, and fidelity are more likely to succeed.

While school food and nutrition-sensitive social protection interventions have shown the potential to promote healthy and sustainable food behavior among school children and mothers (Hoddinott et al., 2018; Oostindjer et al., 2017), they covered only 4% and 2% of the total interventions reviewed. These results may support the assertions that most NSA interventions may focus on food production outcomes.

The cross-cutting interventions, including women empowerment, safety and hygiene, and food waste, have usually been carried out as part of the other dimension intervention. However, there are interventions that are primarily focused on nutrition-sensitive value chains (also considered a cross-cutting dimension) as shown in Figure 4.3C. Such value chain projects have combined nutrition education and other dimensions to measure the impact of agriculture intervention on nutrition. Food quality, safety, and hygiene interventions account for about 3% of the sampled articles. Similarly, interventions that have focused on food losses and food waste also account for about 2%. Although these projects do not typically measure nutrition outcomes, there is a recent report in which nutritional implications for post-harvest losses were quantified (Ellis et al., 2020), thus demonstrating how household nutrition losses could be measured within food production-related interventions.

The results presented on the dimensions show that single-focused intervention may not be adequate to capture the impact of nutrition fully. This has been reflected in most of the selected projects that have used at least two of the dimensions/subdimensions. It points to the fact that multidimensional interventions are becoming the route for project designers and implementers. It also reveals that the global approach to improving nutrition through agriculture has not changed from food production to other dimensions. In fact, it is becoming more focused on food production. This is evident when comparing the result found by Hawkes et al. (2012), when a review of current and planned research on agriculture for improved nutrition was conducted almost a decade ago. The increase in percentage from 43.7% to 63.3% suggests that the trajectory for enhancing nutrition of population and vulnerable subgroups might be food production for the next decade. However, the inclusion of other dimensions that strengthen food systems actors in their capacity has increased, considering that 39.6% of the projects is focused on nutrition education.

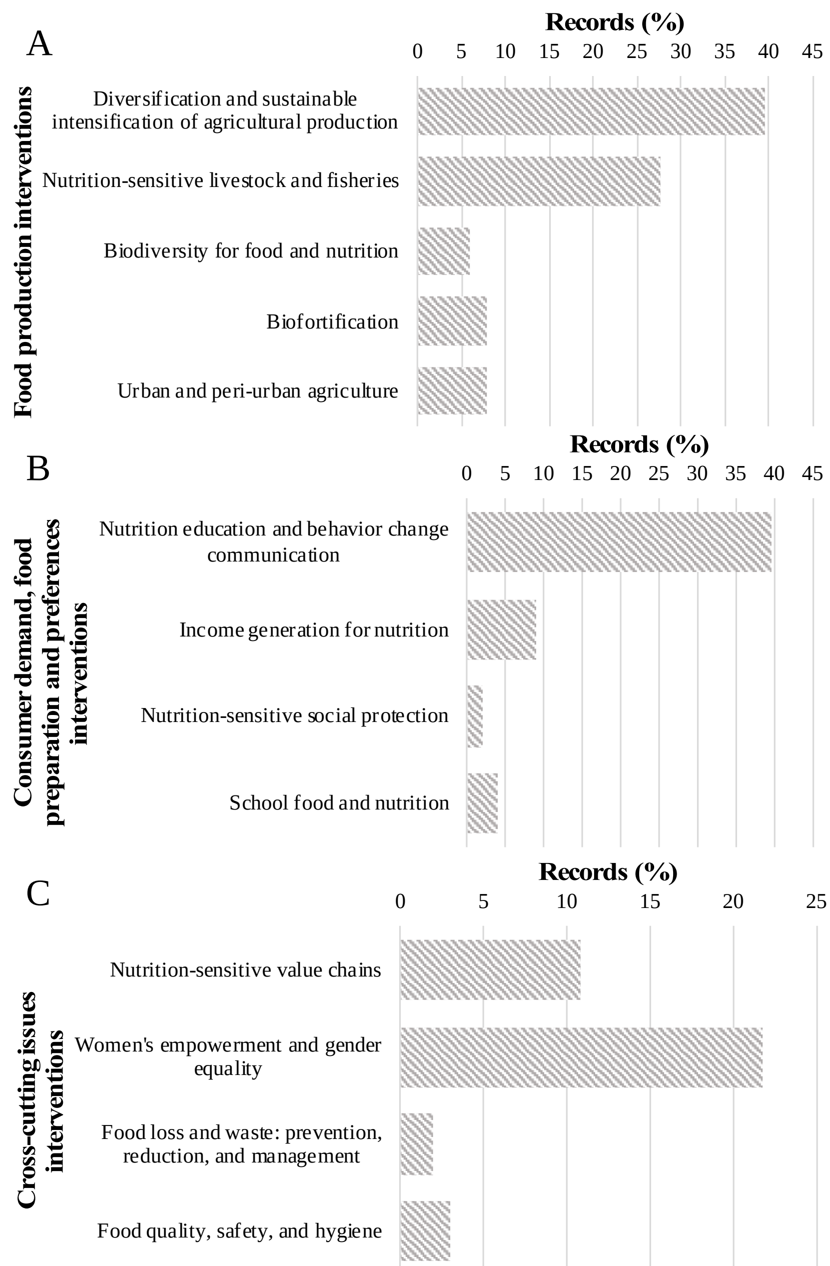

Figure 4.3 Intervention distribution across A) food production, B) consumer demand, food preparation and preferences, and C) cross-cutting issues.

4.5.2 Indicator selection

The accuracy of the measurement of nutrition impact depends on the selection of indicators. The ten-indicator category used to analyze the interventions and how nutrition impact was measured shows that the individual diet quality indicators are the most widely employed (in 61.4% of the reviewed interventions), while the indicators of natural resource management practices, health, and sanitation environment were the least used. Figure 4.4 reveals that the indicators that measure directly the nutrition parameters, such as quality/diversity of food, household access to food, and the anthropometric and biochemical measures are very common indicators. The percentages presented in this report are relatively lower than those reported by Herforth and Ballard (2016). The observed variation could be attributed to the fact that many of the indirect nutrition measuring indicators such as food safety, on-farm availability, care practices, food environment, and sanitation were not fully represented in their evaluation. However, it is important to note that both studies demonstrate the dominance of direct nutrition measuring indicators to assess the impact of nutrition in agriculture interventions.

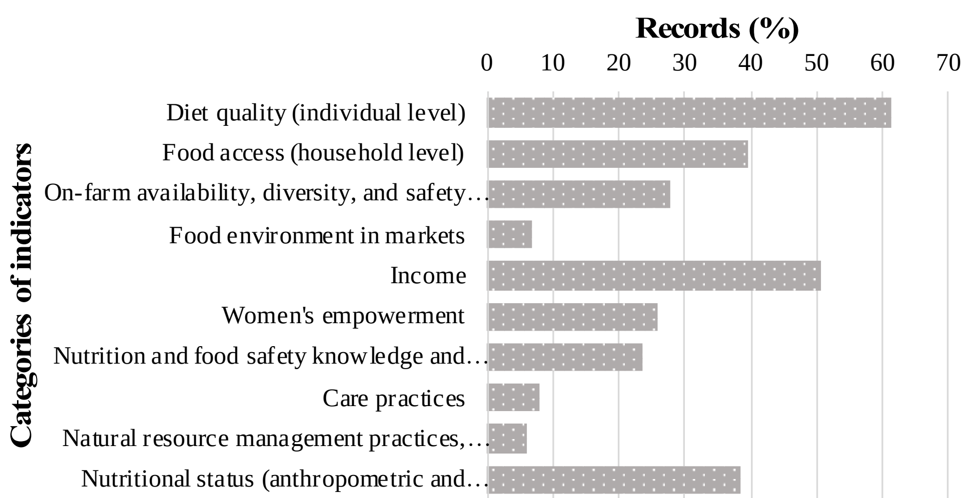

Figure 4.4 Distribution of impact assessment indicator categories.

Apart from income, women’s empowerment, and nutrition and safety knowledge and norms (used in 50.5%, 25.7%, and 23.8% of the sampled studies, respectively), all other indirect nutrition measuring indicators represented a small fraction of the projects (5.9-7.9%). The results suggest that although a multidimensional approach to NSA projects has been viewed as essential for promoting nutrition in the last decade, the evaluation of indirect nutrition parameters is lagging. Fortunately, advocacy for women's empowerment has been gaining relevance over the years, since most of the NSA interventions that took it into account were published from 2019 to date; however, the evidence shows that only a quarter of the studies seem to view it as a significant pathway to improved nutrition. This result is significantly lower than the 53% reported by Herforth and Ballard (2016).

A detailed analysis of the distribution of the four main indicator categories is shown in Figure 4.5. Figure 4.5A shows that Minimum Dietary Diversity for women of reproductive age (MDD-W) (15.8%), Minimum Dietary Diversity for young children (MDD-C) (15.8%), the individual dietary diversity score (IDDS) (17.8%), quantitative nutrient intakes (16.8%) and consumption of specific target foods (15.8%) were the most used individual level diet quality indicators in the sampled studies. While these individual diet quality indicators allow project implementers and researchers to measure the diversity of food consumed by participants, the challenge has been their inability to reflect the adequacy of target nutrients and not provide comprehensive diet quality information. At the household level, the Household Dietary Diversity Score (HDDS) (23.8%) has been the most employed indicator, followed by the Household Food Insecurity Access Scale (12.9%) (Figure 4.5C). The HDDS is also a proxy for measuring household food access and its diversity. Thus, it has the same limitation as to the individual proxy indicators. Wealth indices/poverty levels and income and consumption are the primary indirect nutrition measuring indicators used (Figure 4.5B), representing 22.8% and 21.8%, respectively, of the reviewed studies.

Figure 4.5D shows the nutritional status indicators identified in the NSA interventions, which are divided in two types: anthropometric and biochemical measures. An important observation from the analysis compared with the report from Herforth and Ballard (2016) was the reduction in interventions that focused on nutritional status measurement. In their conclusion, they highlighted the need to move away from nutritional status towards more proximal outcomes (diet and food access) that could significantly impact nutrition. The current results seem to reflect this shift in intervention focus.

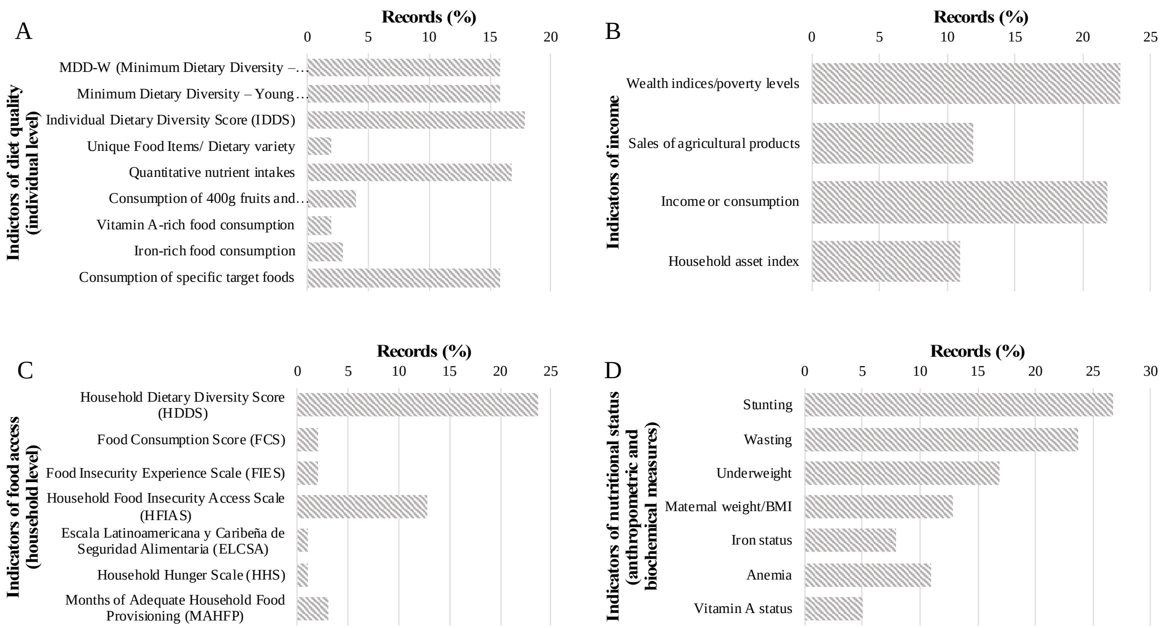

Figure 4.5 Nutrition impact assessment indicators A) Diet quality, B) Income, C) Food access and D) Anthropometric.

4.5.3 NSA intervention methodological validity and enabling environment

The reliability of evidence provided by NSA interventions to inform policymaking depends on the validation process's robustness. The results of the methodological validity of the interventions analyzed are presented in Figure 4.6. Almost half of the interventions (44.6%) had a medium score for counterfactual analysis. This was mostly due to the fact that randomized control trials (RCT) are challenging to implement in large food systems, where the effects of pathways are long, and the introduction of new evidence-based policies are desperately needed. On the other hand, it has been recorded that, small, local, internal projects (e.g., home gardens), even when they show appropriate RCT, might not be useful because they could not show external validity that can trigger a change in the food system (Pinstrup-Andersen, 2013).

About two thirds (65.3%) of the selected interventions worked with samples that were smaller than the necessary to validate power. This is consistent with the observation made by Herforth and Ballard (2016). This can be attributed to the lack of adequacy of the intervention context, where implementing RCT interventions is a difficult task (Pinstrup-Andersen, 2013). For most interventions, the same sample size usually estimated based on the primary indicator is used throughout the project period. Masset et al. (2011) observed that different indicators might require different power calculations to notice statistically differences among different groups. For instance, the sample size for detecting the impact of a vitamin supplementation intervention would not be adequate for a prevalence of malnutrition within the same project.

The external validity was divided into two parts: program theory and heterogeneity. The program theory was relatively spread across the three scores (Figure 4.6). It can be said that about 38.6% of the selected studies had estimated intermediate outcomes, and that 33.7% considered intermediate outcomes in the interventions design. In more than 60% of studies, heterogeneity was not analyzed or considered, which means that it becomes difficult to extrapolate the results regarding their impact so that one can apply the same methodology in different contexts. In a systematic review of agriculture interventions aimed at improving the nutritional status of children, Masset et al. (2011) also found that heterogeneity is considered a concern of the literature.

The enabling environment has an impact on the availability of food in the market (Jaenicke and Virchow, 2013). For example, international trade policies may increase the availability of imported food products that could consequently have an impact on local diets, or the tax policies may favor the access to nutrient-dense foods. Out of the sampled studies, 43.1% were conducted in populations where the enabling environment was graded as “to some extent”, whereas 41.2% were performed in populations where the enabling environment was graded as “not really” and “not at all”, and not a single population had an enabling environment graded as “very much”. These results point to the fact that project implementers have to consider the characteristics of the populations and the context within which a project is rolled out to collect reliable and adaptable data to enhance evidence-based policies in order to improve the enabling environment.

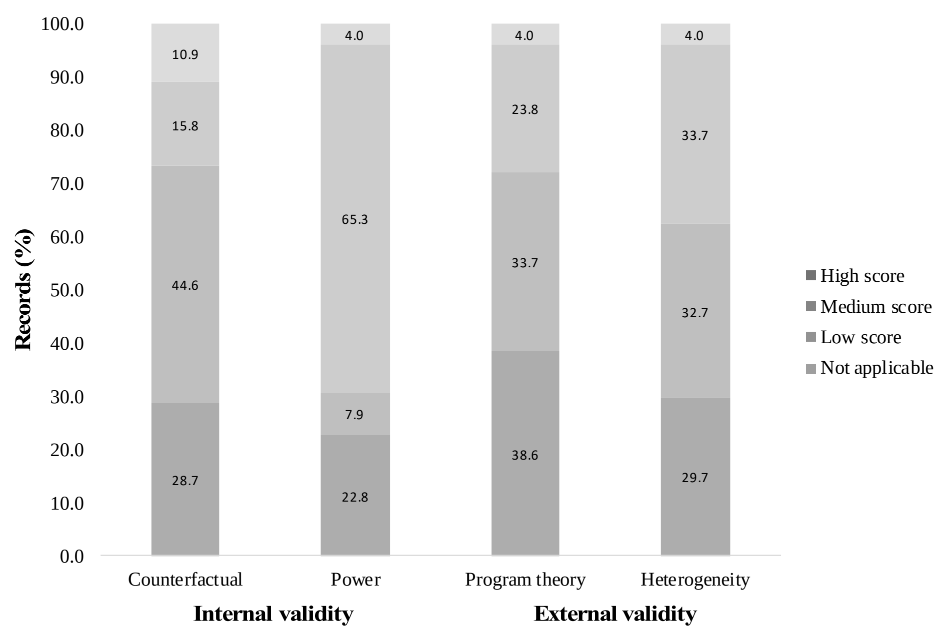

Figure 4.6 Methodological validity analysis of the selected interventinos.

4.6 Discussion

The understanding of the impact of agriculture on nutrition and the ability to measure and use the result in formulating policy and future intervention is dependent on the indicator used and the methodological validity. Current projects showed to be largely designed within the food production dimension. They rely mainly on the direct nutrition parameter indicators, such as the individual and household diet diversity indicators.

In terms of diet quality parameters, we found that the Minimum Dietary Diversity Score for 6-23-month-old children (MDD-C) was designed by the World Health Organization (WHO) to assess the diet diversity as part of an infant and young child feeding (IYCF) practices among children. The MDD-C is among eight other indicators developed by WHO to gather simple, valid, and reliable data for assessing IYCF practices (WHO, 2008). As mentioned above, the MDD-C indicator was used in 15.8% of the analyzed studies (Ambikapathi et al., 2021; Berti et al., 2016; Bonis-Profumo et al., 2021; Bonuedi et al., 2022; Boulom et al., 2020; Desalegn and Jagiso, 2020; Gebremedhin et al., 2017; Guja et al., 2021; Kadiyala et al., 2018, 2021; Marquis et al., 2018; Mashingaidze et al., 2020; Muthini et al., 2020; Passarelli et al., 2020; Santoso et al., 2019; Sharma et al., 2021b). The projects in which the MDD-C indicator was selected tended to belong to the dimension of nutrition education and behavior change communication. Young children are among the most susceptible to suffer from different forms of undernutrition. Therefore, interventions that aim to increase nutrition knowledge should consider the IYCF practices, and the MDD-C indicator is a good choice to assess such practices. This indicator was also used in interventions with the dimensions of diversification and sustainable intensification of agricultural production, nutrition-sensitive livestock and fisheries, and women's empowerment and gender equality. To a lesser extent, the MDD-C indicator was chosen in NSA studies of food quality, safety and hygiene.

The use of the MDD-C indicator was associated with the HDDS as well as the IDDS and the MDD-W. The studies that chose the MDD-C indicator had a pathway that followed care practices (e.g., through women's empowerment, agricultural training, nutrition knowledge) and food access (income and consumption) to improve diet quality and, in some cases, nutritional status. Gupta et al. (2019) reported that women's empowerment has the potential to reduce iron deficiency in women. Women's empowerment included different domains, such as spousal communication, purchasing decisions, health care decisions, and family planning decisions. Heckert et al. (2019) found that empowering women was, in fact, beneficial not only for women's lives but also for their children's nutrition. Hence, the inclusion of an indicator such as MDD-C is advisable in interventions that follow the women's empowerment pathway.

The MDD-W indicator determines whether or not women 15-49 years of age have consumed at least five out of ten defined food groups the previous day or night. The MDD-W was used across 15.8% of the selected projects (Ambikapathi et al., 2021; Bernet et al., 2018; Blakstad et al., 2019; Bonis-Profumo et al., 2021; Bonuedi et al., 2022; Chagomoka et al., 2018; Connors et al., 2021; Gebremedhin et al., 2017; Gelli et al., 2017; Guja et al., 2021; Gupta et al., 2019; Haghparast-Bidgoli et al., 2019; Kadiyala et al., 2021; Mashingaidze et al., 2020; Muthini et al., 2020; Santoso et al., 2019). The results show that although MDD-W can be used across various types of interventions, it is mostly used in projects that focus on one of the following: diversification and sustainable intensification of agricultural production; nutrition education and behavior change communication; and women's empowerment and gender equality. Additionally, the MDD-W is always used together with other indicators in nutrition impact evaluation. As noted by FAO (2016), the MDD-W is validated and easy to administer, but it does not capture dietary quality completely because, even when it measures micronutrient adequacy and diversity, it does not take into account the unhealthy amounts or components of the diet (e.g., recommended daily intake of sugar). The analysis of the interventions indicates MDD-W is mainly used together with other diet quality indicators such as the MDD-C, or Household Food Access indicators, such as HDDS. Other dietary quality scores have been proposed (e.g., the healthy eating index), but they require a full quantitative 24 h recall.

The analysis of projects that used the MDD-W to determine their impact reveals that such projects focused not only on interventions related to food production, but also on interventions involved in consumer demand, food preparation and preferences. However, the impact of seasonality is an important factor for consideration when using the MDD-W. For instance, Kennedy and Ahern (2019) found that for the same household within a selected community, the fraction of women of reproductive age meeting the MDD-W threshold could vary between 18 and 79% throughout the year. In interventions that had measured in addition to the functional diversity, the various dimensions of food and nutrition security as well as nutritional quality and yield of the agricultural production systems, their results reflected the degree of variability in nutritional yields. These interventions also revealed the need to prioritize the context and focus on existing micronutrient deficiencies.

The IDDS aims to reflect nutrient adequacy. According to Kennedy et al. (2011), the increases in IDDS values have been related to increased nutrient adequacy of the diet, regardless of the age of the people in the studied groups. The IDDS indicator was used in 17.8% of the sampled studies (Bhaskar et al., 2017; Busse et al., 2018; Dangura and Gebremedhin, 2017; Depenbusch et al., 2021; Desalegn and Jagiso, 2020; Headey and Hirvonen, 2016; Jones, 2015; Kadiyala et al., 2018; Kassie et al., 2020; Koppmair et al., 2017; Mamun et al., 2021; McMullin et al., 2019; Melesse, 2021; Rosenberg et al., 2018; Sharma et al., 2021b; Shrestha et al., 2020;

Singh and Fernandes, 2018; Verbowski et al., 2018).

This IDDS indicator was strongly associated with interventions that correspond to the type of nutrition education and behavior change communication. This makes sense because it is important to determine if, in fact, a project based on nutrition education helps improve the eating habits where the intervention takes place. The IDDS indicator was also associated with types of interventions of diversification and sustainable intensification of agricultural production, nutrition-sensitive livestock and fisheries, women's empowerment and gender equality and, to a lesser extent, to biodiversity for food and nutrition, trade for nutrition, school food and nutrition, nutrition-sensitive value chains, and food quality, safety and hygiene.

It is important to note that the IDDS indicator was usually chosen with the MDD-C and the HDDS. These three indicators aim to measure how diverse the diets are in the communities where the interventions took place.

The studies that chose the IDDS indicator tend to have a similar pathway to those that chose the HDDS. One study took into account the pathway of care practices through income and consumption with respect to household and community diets (Blakstad et al., 2019). In that study, the authors found that home gardening influenced the diet of neighboring households, and that through homestead vegetable production, individuals may increase their purchasing power by selling vegetables at local markets or by saving the money they otherwise would have spent on food. Glover-Amengor et al. (2016) agree that, apart from improving the socioeconomic and household food security status, the implementation of home gardening and keeping poultry can improve the quality of children's diets.

According to Swindale and Bilinksy (2006), a more diversified household diet is correlated with caloric and protein adequacy, percentage of protein from animal sources, and household income. The HDDS indicator is useful to get a notion of a household's ability to access diverse food. Therefore, it gives an idea of the household's socioeconomic status based on the previous 24 hours (Kennedy et al., 2011). As shown above, the HDDS indicator was used in 27.5% of the analyzed articles (Baudron et al., 2017; Bogard et al., 2018; de Bruyn et al., 2019; Gebremedhin et al., 2017; Gupta et al., 2019; Koppmair et al., 2017; Rosenberg et al., 2018; Sibhatu et al., 2015; Sibhatu and Qaim, 2018b, 2017).

The selection of the HDDS indicators was highly correlated to the dimensions of diversification and sustainable intensification of agricultural production and, to a lesser extent, to nutrition-sensitive value chains. In theory, the household diet is expected to be more diverse if food production is diversified. This, however, might not be the case if the people of community are not aware of the healthy food products that they can get. Therefore, it is not surprising that the HDDS indicator is also used when interventions fall into the dimension of nutrition education and behavior change communication.

In the studies where the HDDS indicator was chosen, MDD-W, MDD-C were also chosen. It is recommended to assess the household's dietary diversity, but it is interesting to compare it to indicators that measure individual dietary diversity.

The studies that chose the HDDS indicator tend to have a pathway that follows the food access (through farm production and purchased production) and care practices (through increasing knowledge) to improve the diet quality. Results suggest that increasing farm production diversity is not as efficient as strengthening markets and smallholder markets, and productivity-enhancing inputs and technologies (Koppmair et al., 2017; Sibhatu and Qaim, 2018b, 2017). Bogard et al. (2018) emphasize focusing on the existing micronutrient deficiencies in the population rather than attempting to optimize nutritional yields across all nutrients.

A total of 21.8% of studies examined the income or consumption linkages to nutritional status (Bagson and Kuuder, 2013; Bernard et al., 2019; Bhaskar et al., 2017; Bonuedi et al., 2022; Boulom et al., 2020; Burney et al., 2010; Carletto et al., 2017; Connors et al., 2021; Gelli et al., 2017; Kabunga et al., 2014; Kjeldsberg et al., 2018; Leight et al., 2021; Mashingaidze et al., 2020; Melesse, 2021; Nordhagen and Traoré, 2021; Peter, 2011; Ramos et al., 2021; Rosenberg et al., 2018; Rukmani et al., 2019; Sibhatu et al., 2015; Sinyolo et al., 2021, 2014). These studies belonged mostly to food production interventions, especially diversification and sustainable intensification of agricultural production, and nutrition-sensitive livestock and fisheries. Interventions from the income generation for nutrition and women's empowerment types also used income or consumption indicators. To a lesser extent, nutrition-sensitive value chains measured income or consumption as well. The assessment of the impacts of these interventions was achieved in diverse dimensions and indicators. The income/consumption indicator was used with several other indicators for food access, diet quality assessment, and on-farm availability, diversity and safety of food. The indicators that were combined the most with income/consumption were diversity of foods produced on-farm, HDDS, MDD-C, MDD-W, and IDDS.

The assessment of the intervention outcomes from the income/consumption indicator showed some interesting results. Whereas diversification and sustainable intensification of agricultural production dimension has the benefit of providing adequate and diverse food, the income-generation for nutrition has the potential to provide high levels of agricultural produce for commercialization, even for the poorest households. Furthermore, the combination of nutrition value chains and women empowerment are non-dietary pathways to address a nutrient deficiency in women. However, interventions aim at improving nutrition through diet but lacking in diversity and without nutrition-sensitive farming systems may not be appropriate to achieve positive nutritional impact or health status. In this view, a contextual framework should be considered in the design of NSA interventions.

Stunting is an anthropometric measure of the low height-for-age. Stunted growth occurs due to a process of failure to reach the growth potential as a result of suboptimal health and/or nutritional conditions (WHO, n.d.). The stunting indicator was chosen in 26.7% of the analyzed studies (Boulom et al., 2020; Busse et al., 2018; Carletto et al., 2017; Dumas et al., 2018; Gelli et al., 2017; Glover-Amengor et al., 2016; Gowele et al., 2021; Hagos et al., 2017; Headey and Hirvonen, 2016; Hotz et al., 2012b; Jones, 2015; Mamun et al., 2021; Marquis et al., 2018; Mashingaidze et al., 2020; Melesse, 2021; Michaux et al., 2019; Miller et al., 2017; Mosquera Vasquez et al., 2017; Olney et al., 2015; Passarelli et al., 2020; Rakotomanana et al., 2020; Santoso et al., 2021; Schreinemachers et al., 2017a, 2017b; Sharma et al., 2021b; Sibhatu and Qaim, 2017; Verbowski et al., 2018).

Hidden hunger is expected to be reduced when diet becomes more than staple crops such as maize, wheat, and rice. If the diet is rich in fruits, vegetables, pulses, and protein from animal sources, children are more likely to get the essential micronutrients (e.g., vitamins, minerals, and amino acids) for optimal growth. Therefore, it makes sense that the selection of the stunting indicator was associated with types of interventions, such as diversification and sustainable intensification of agricultural production, nutrition-sensitive livestock and fisheries, and nutrition education and behavior change communication.

The studies that chose the stunting indicator tended to also choose the underweight and wasting (low weight-for-height) indicators, which complete the anthropometric measure of children. Studies that assessed stunting chose pathways that followed food access through biofortified crops (Hotz et al., 2012b; Mosquera Vasquez et al., 2017), optimization of livestock management (Miller et al., 2017), and food production (Marquis et al., 2018); care practices through income (Carletto et al., 2017) and knowledge and awareness of healthy foods (Busse et al., 2018; Schreinemachers et al., 2017a, 2017b). As an anthropometric indicator, stunting measures the nutritional status of children, which is the endpoint of the full nutritional pathway. When selecting an indicator to measure the nutritional status, it is important to also select indicators that assess the impact of the intervention in previous steps of the process. The intervention should be lasting enough to perceive any significant changes in anthropometric or biochemical measures. For instance, Dumas et al. (2018) determined that, despite the increased egg consumption in rural Zambia, there was no impact on the height for age of children due to the fact that there was a short follow-up time and relatively modest dose of egg consumption. Future work should further investigate the adequate duration of an intervention for biochemical and anthropometric measures to be used, because these can be quite invasive for the subjects.

The limitations of this systematic review should be acknowledged. First, comparisons of the numerical results (e.g., MDD-W from different sampled studies with the same type(s) of interventions) were not included, and that would have shaded some light into the discussion of what context conditions are more suitable for each type of intervention as well as the proper indicator selection. Second, due to the fact that the selected studies were performed in very different contexts, a high heterogeneity is expected for the analyses.

4.7 Conclusion

In conclusion, this work revealed that projects designed with a multidimensional focus seem to employ more indicators in measuring impact on nutrition. Thus, such interventions are able to use both the direct nutrition parameters as well as the indirect nutrition indicators such as food environment, women’s empowerment, natural resource, health, and sanitation. As the demand for a sustainable healthy diet grows, measurement of impact must look beyond diet quality to fully capture all the necessary bits. The biggest challenge from a methodological validity point of view was the low statistical power in many interventions (65.3%) which limited the adaptability of results to other context and inability to detect changes to ascertain the impact of these interventions. Future work should focus on the duration of certain type NSA interventions to notice significant changes in the outcomes that are to be measured. It is important that project designers and implementers give adequate consideration to ensure the results become more useful to improve the enabling environment of the populations.

CONNECTING TEXT

The most significant interventions, in terms of the frequency with which they are selected when designing an NSA project, have been identified: food production and consumer-focused. Women's empowerment, which is a cross-sectional issue, has gained relevance over the years, and the indicators most commonly used are those that measure diet quality, food access, and nutritional status. It was observed that two third of the studies had issues with a proper design (e.g., power and sample size, not choosing indicators to measure impacts established in their Theory of Change). Therefore, there is a need of a tool to help improve the design of NSA projects that follow multi-pathway approaches.

Chapter V focuses on the fourth objective of this thesis, i.e., to explore the feasibility of Multi-Criteria Decision Analysis (MCDA) in developing the technological tool to design and evaluate the NSA intervention(s) (to use the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), to determine, based on the context of the community and the priorities of the project managers or designers, the NSA interventions that are the most suitable for the target community, and to create a selection criterion to fit a chosen algorithm (using MCDA) for the most appropriate pathways, metrics and indicators, and to associate them with the questions required to gather the data). Chapter V has been prepared to be submitted to *Agriculture and Human Values*. It is co-authored by Dr. Michael Ngadi, Dr. Christopher Kucha, and Dr. Ebenezer Kwofie.

V. TOPSIS AS A TOOL TO DESIGN NUTRITION-SENSITIVE AGRICULTURE (NSA) INTERVENTIONS

5.1 Abstract

When it comes to designing nutrition-sensitive agriculture (NSA) projects, there are too many types of interventions, metrics and indicators, which leads to a risk of choosing some that are not the most adequate for a specific context. By using a questionnaire that pondered the objectives and priorities of a project manager, ranked lists of types of NSA interventions were obtained with the closeness values (CV) from the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The Bolivian, Laotian, and Ethiopian contexts in terms of nutrition and food security were considered for weighting the TOPSIS decision matrix. The top three types of interventions were: Nutrition education and behavior change communication, nutrition-sensitive livestock and fisheries, and diversification and sustainable intensification of agricultural production (CV = 0.6157, 0.5921, and CV = 0.5456, respectively). When looking at the indicators, based on the points from the responses of the questionnaire, the most relevant ones were changes in specific behaviors promoted about food safety, nutrition and food safety-related knowledge, breastfeeding indicators. We built a framework for a technological tool capable of evaluating the baseline agriculture-nutrition nexus, and any changes after the intervention(s) take(s) place. This research will be useful for NSA project managers and designers.

Keywords: Nutrition-sensitive agriculture (NSA), Food systems, Multi Criteria Decision Analysis (MCDA), TOPSIS

5.2 Introduction

Nutrition-sensitive agriculture (NSA) is an approach that seeks to ensure, in a sustainable manner, the production of a variety of affordable, nutritious, culturally appropriate, and safe foods in sufficient quantity and quality to meet the dietary requirements of a population (FAO, 2017). The ultimate goal of NSA projects is to improve the nutritional status of vulnerable communities by addressing the underlying causes of nutrition (e.g., access to safe and nutritious food, nutrition knowledge and norms, income, women's empowerment) (Herforth and Ballard, 2016). FAO (2017) indicates the principles that should be taken into account when designing an NSA intervention. Besides assessing the context of the target population(s), they recommend collaborating with different sectors and programs (e.g., government, health, nutrition) and incorporating nutrition objectives and indicators in the design, as well as nutrition promotion and education. They also provide a list of possible NSA interventions, which are classified based on the main functions of the food system or cross-cutting issues.

Appropriate indicators are necessary to measure the impact of an NSA project. The selection of the indicators depends on the pathway(s) that the intervention(s) follow(s). FAO (2016) offers a compendium of over 60 indicators, classified into 10 categories: diet quality; food access; on farm availability, diversity and safety of food; food environment in markets; income; women's empowerment; nutrition and food safety knowledge and norms; care practices; natural resource management practices, health and sanitation environment; and nutritional status (anthropometric and biochemical measures).

There are still some gaps when it comes to designing NSA interventions. For example, each project needs to be analyzed ex ante for a clear theory of change. Sometimes it is not very clear what interventions are the most suitable for a certain community. Besides, the most appropriate indicators will vary, depending on the nature of the intervention and the pathway that it follows. Since there are too many metrics and indicators, it can be difficult to keep track of what each one reflects, which leads to a risk of misinterpreting them and/or choosing some that are not the most adequate. Verger et al. (2019) reviewed 46 peer reviewed studies and they found that, at the household level, half of the studies were not consistent in terms of use and interpretation of simple food group dietary diversity indicators; the interpretation, for instance, was misleading in some cases (e.g., interpreted results of household dietary diversity score (HDDS) as a measure of diet quality, household nutrition or nutritional status when it really is a measure of food access).

Multi-criteria decision analysis (MCDA) involves different methods that support the decision maker in their unique and personal decision process, providing stepping-stones and techniques for finding a solution (Ishizaka and Nemery, 2013). MCDA has been used to resolve complex problems related to agriculture, such as soil erosion and degradation (Grau et al., 2010), measuring the sustainability level of agricultural systems (Talukder et al., 2018, 2016), interpretation of stakeholders' multidimensional perceptions on policy implementation gaps regarding small-scale seaweed aquaculture (Henríquez-Antipa and Cárcamo, 2019), tillage practices to mitigate negative environmental impact to soils (Król et al., 2018), finding the suitable zones of peri-urban agriculture (Majumdar, 2020), development of strategically located land index to identify land suitable for agricultural land reform or for cultivation priority planning of different crops (Musakwa, 2018; Seyedmohammadi et al., 2018).

In this work, we propose the development of a technological tool that not only helps design NSA projects, but also can be used to assess the agriculture-nutrition nexus, which, as explained by Estrada-Carmona et al. (2020), is affected by multifaceted, ever-changing and scale-dependent interlinkages among farms, markets, wild foods, diets, intra-household and gender dynamics. To our knowledge, MCDA has not been used to design NSA interventions. Therefore, this work aims to integrate the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), an MCDA method, into the development of a technological tool for that purpose.

5.3 Methodology

5.3.1 Questionnaire

A multiple-choice questionnaire was designed (shown in Appendix A1 of this thesis). The focus of NSA projects, in broad terms, is to understand the relationship between food production and the health among the households from the target community. This relationship may be studied by looking at the different pathways that go from agriculture to nutritional status (Herforth and Ballard, 2016). The aim of the questionnaire that was developed here was to make a preliminary assessment of the potential pathway(s) that the user may follow to succeed in their nutrition objectives.

The first question is about the duration of the intended project, which can be “weeks”, “months” or “years”. The duration is key to know if considering some indicators is worth it. For instance, findings from our meta-analysis suggest that anthropometric measures (i.e., stunting, wasting, underweight) are not recommended when the NSA interventions last less than one year, because it takes longer to observe significant changes in these indicators.

There are a few “yes” or “no” questions that determine if the target community performs agricultural activities, if there is an intention to change the agricultural landscape, and/or if the planned intervention is focused on technology for behavior change communication (BCC) (e.g., development of apps, webpages or video commercials to spread key messages on nutrition). Other “yes” or “no” questions are included to determine if collecting data on nutritional status (i.e., anthropometric and biochemical measures) is relevant for the respondent.

The rest of the questionnaire is comprised of multiple-choice questions that assess the importance of certain issues (e.g., health status of children from different ages health status of women or reproductive age). The indicators from the compendium that the FAO (2016) offers are organized into 10 categories (e.g., diet quality, food access, nutritional status). The compendium was used as a guideline to make sure that each step of the possible pathways was addressed by the 97 questions.

5.3.2 Percentages according to the type of indicators

The next step was to distribute percentual points into the indicators from the different categories. Table 5.1 shows a sample of how percentages were assigned. For example, when the intervention intends to last one or more years, biochemical measures (e.g., anemia, vitamin A status) have higher percentages than when the intervention intends to last months or weeks. On the other hand, the indicators that measure diet quality gain relevance when the project is planned for a short period.

Some questions are not for categories, they target specific indicators. For instance, the question “How important is it to know if the individuals are meeting the WHO recommendations for fruits and vegetables consumption?” is to determine if the indicator of “Consumption of 400 g fruits and vegetables per day” is useful for the project. Therefore, that question has a 95% assigned for that indicator; the remaining 5% was distributed equally among the rest of the indicators.

Table 5.1 Percentages of importance assigned to each indicator for each question.

Questions	MDD-W	MDD for young children	IDDS	…	Anemia	Vitamin A status	SUM
1. How long does the intervention intend to last?							
a. Years	0.14%	0.14%	0.14%		5.00%	5.00%	100%
b. Months	3.00%	3.00%	3.00%		0.24%	0.24%	100%
c. Weeks	3.00%	3.00%	3.00%		0.17%	0.17%	100%
2. Is it for an agriculture-based community?	2.00%	2.00%	2.00%		0.18%	0.18%	100%
3. How important is it to know the economic food access of a household?	0.13%	0.13%	0.13%		0.13%	0.13%	100%
…							
90. Are you planning to determine whether women of reproductive age are deficient or replete in vitamin A?	0.09%	0.09%	0.09%		0.09%	95.00%	100%

5.3.3 Points for the user's responses

The next step was to assign points to the user's responses. Each answer had up to 10 points. In the case of the duration, the whole 10 points went to the user's selection. For the yes or no questions, the 10 points were for the affirmative responses. For the questions that assess the relevance or importance of different issues, a scale that goes from 0 to 10 was assigned, as shown in Table 5.2.

Table 5.2 Possible answers for the different types of questions of the questionnaire.

Duration	**Y/N questions**	**Relevance or Importance**
Months	Yes (10)*	Very important (10)
Weeks	No (0)	Important (7.5)
Years		Somewhat important (5)
		Not very important (2.5)
		Does not apply (0)

The points of each answer were distributed among the different indicators, based on the percentages that were assigned in the previous section. Table 5.3 shows a sample of a project that is intended to last one or more years. As seen in Table 5.1, Anemia and Vitamin A status have a 5% for this duration. This is why there are 0.5 points for these indicators in Table 5.3 (5% of 10 is 0.5). Vitamin A status has 9.5 points for the question regarding the plans to determine whether women are deficient or replete in Vitamin A, because this indicator has a 95% for that question (Table 5.1).

The accumulated points of each indicator (sums in each column) were calculated and used as the values for the TOPSIS methodology. As seen in Table 5.3, biochemical measures (Anemia and Vitamin status) are the indicators with the highest values, followed by MDD for young children, which is one of the indicators that assess the diet quality at the individual level.

Table 5.3 Accumulated points for each indicator, resulting from multiplying the points from the responses by the percentages of importance from Table 5.1.

Questions	**MDD-W**	**MDD for young children**	**IDDS**	**…**	**Anemia**	**Vitamin A status**
1. How long does the intervention intend to last?						
a. Years	0.01	0.01	0.01		0.50	0.50
b. Months	0.00	0.00	0.00		0.00	0.00
c. Weeks	0.00	0.00	0.00		0.00	0.00
2. Is it for an agriculture-based community?	0.20	0.20	0.20		0.02	0.02
3. How important is it to know the economic food access of a household?	0.01	0.01	0.01		0.01	0.01
…						
90. Are you planning to determine whether women of reproductive age are deficient or replete in vitamin A?	0.01	0.01	0.01		0.01	9.50
Accumulated points	**13.19**	**16.80**	**7.59**		**24.88**	**24.88**

5.3.4 TOPSIS method

There are many factors that should be considered when designing NSA projects. Berti et al. (2016) developed a framework taking into account community factors (e.g., agricultural production), project factors (e.g., budget) and external factors (e.g., government agencies involved in current NSA projects in the target community) that were helpful to identify the NSA interventions that were most likely to have a positive impact on agricultural and nutritional outcomes. In our study, however, we aimed at developing a technique with which it was possible not only to identify the most suitable interventions but also to rank them, as objectively as possible, from the most to the least recommended NSA interventions.

As previously discussed, the MCDA is a powerful tool that may help the decision maker choose the best options, based on different attributes. Among the several MCDA methods, we chose the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) because it requires a relatively minimal number of inputs from the user and its output is easy to understand. Besides, TOPSIS has several advantages, such as: a scalar value that accounts for both the best and worst alternatives simultaneously; a sound logic that represents the rationale of human choice; the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions; and a simple computation process (Kim et al., 1997). These advantages make TOPSIS a major MCDA method as compared with other related methods, such as AHP and ELECTRE (Kahraman et al., 2009). The only subjective parameters in the TOPSIS method are the weights associated with the criteria.

The fundamental idea of TOPSIS is that the best solution is the one which has the shortest distance to the ideal solution and the furthest distance from the anti-ideal solution. As explained by Ishizaka and Nemery (2013), the TOPSIS method is based on five computation steps that are described in the sections below.

5.3.4.1 Distributive normalization

A total of 101 studies (from 2010 to 2022) were subjected to a meta-analysis to categorize them into the different types of NSA interventions according to FAO (2017). An analysis of the used indicators was also performed. Based on the frequency with which the indicators were used for each type of intervention, percentages were assigned. For example, the IDDS indicator was used 25 times in total, 6 of which (24%) were used to assess the interventions that belong to the category of Nutrition Education and Behavior Change communication (Table 5.4).

The accumulated points previously obtained were multiplied by their corresponding percentage. For instance, the Anemia indicator had a total of 24.88 accumulated points, which were multiplied by 13.64% for both *Diversification and sustainable intensification of agricultural production*, and *Nutrition-sensitive livestock and fisheries*, which is 3.39, as shown in Table 5.4.

The right section from Table 5.4 is the decision matrix (X = x_{ia}), in which one can see the performance of n alternatives a (types of NSA interventions) with respect to m criteria i (indicators), where i = 1,…, m and a = 1,…, n. The attributes may have different units. Therefore, to compare the different criteria (the indicators, in this case), a normalization is required when using TOPSIS. The distributive normalization requires that the performances are divided by the square rut of the squared summation of each element in a column, as indicated by the following equation:

$$r_{ia} = \frac{x_{ia}}{\sqrt{\sum_{a=1}^{n} x_{ia}^2}} \text{ for } a = 1, \dots, n \text{ and } i = 1, \dots, m \qquad (1)$$

This step of TOPSIS, however, was not indispensable for us because all the criteria had the same "dimensions." Instead, we multiplied the accumulated points by the frequency percentages, as shown in table 5.4.

Table 5.4 Decision matrix for TOPSIS: the types of interventions are the different choices whereas the indicators represent the attributes. The percentages are based on the number of times that the indicators were used in each NSA intervention; the accumulated points from Table 5.3 were multiplied by those percentages.

	Percentages						Accumulated					
Types of interventions	**MDD-W**	**MDD for Young children**	**IDDS**	…	**Anemia**	**Vitamin A status**	**MDD-W**	**MDD for Young children**	**IDDS**	…	**Anemia**	**Vitamin A status**
Diversification and sustainable intensification of agricultural production	13.79%	9.85%	14.98%		12.58%	13.03%	0.40	0.23	0.44		0.37	0.44
Nutrition-sensitive livestock and fisheries	6.90%	19.70%	11.24%		12.58%	13.03%	0.20	0.47	0.33		0.37	0.44
Biodiversity for food and nutrition	6.90%	1.97%	7.49%		4.19%	6.51%	0.20	0.05	0.22		0.12	0.22
Biofortification	1.38%	1.97%	1.50%		4.19%	6.51%	0.04	0.05	0.04		0.12	0.22
Urban and peri-urban agriculture	13.79%	19.70%	3.75%		4.19%	6.51%	0.40	0.47	0.11		0.12	0.22
Nutrition-sensitive post-harvest handling, storage, and processing	1.38%	1.97%	0.75%		2.10%	3.26%	0.04	0.05	0.02		0.06	0.11
Food fortification	1.38%	1.97%	0.75%		4.19%	3.26%	0.04	0.05	0.02		0.12	0.11
Trade for nutrition	0.69%	0.99%	7.49%		4.19%	6.51%	0.02	0.02	0.22		0.12	0.22
Food marketing and advertising practices	0.69%	0.99%	0.37%		0.21%	0.33%	0.02	0.02	0.01		0.01	0.01
Food price policies for promoting healthy diets	0.69%	0.99%	0.37%		0.21%	0.33%	0.02	0.02	0.01		0.01	0.01
Food labeling	0.69%	0.99%	0.37%		0.21%	0.33%	0.02	0.02	0.01		0.01	0.01
Nutrition education and behavior change	20.69%	29.56%	22.47%		20.96%	6.51%	0.60	0.70	0.66		0.61	0.22

communication												
Income generation for nutrition	6.90%	1.48%	1.50%		4.19%	6.51%	0.20	0.04	0.04		0.12	0.22
Nutrition-sensitive social protection	0.69%	1.48%	3.75%		0.21%	0.33%	0.02	0.04	0.11		0.01	0.01
School food and nutrition	0.69%	1.48%	7.49%		0.21%	0.33%	0.02	0.04	0.22		0.01	0.01
Nutrition-sensitive humanitarian food assistance	0.69%	0.99%	0.37%		0.21%	0.33%	0.02	0.02	0.01		0.01	0.01
Nutrition-sensitive value chains	6.90%	0.99%	7.49%		4.19%	6.51%	0.20	0.02	0.22		0.12	0.22
Women's empowerment and gender equality	13.79%	0.99%	3.75%		16.77%	13.03%	0.40	0.02	0.11		0.49	0.44
Food loss and waste: prevention, reduction, and management	0.69%	0.99%	0.37%		0.21%	0.33%	0.02	0.02	0.01		0.01	0.01
Food quality, safety, and hygiene	0.69%	0.99%	3.75%		4.19%	6.51%	0.02	0.02	0.11		0.12	0.22
SUM	100.00%	100.00%	100.00%		100.00%	100.00%						

5.3.4.2 Weighting the normalized values

The different indicators can be fitted into 10 categories: 1) diet quality, 2) food access, 3) On-farm availability, diversity and safety of foods, 4) Food environment in markets, 5) Income, 6) Women's empowerment, 7) Nutrition and food safety knowledge and norms, 8) Care practices, 9) Natural resource management practices, health and sanitation environment, and 10) Nutritional status (i.e., anthropometric and biochemical measures). The importance of these categories will depend not only on the context of the target community, but also on external factors (e.g., NGOs, researchers, or government agencies involved in projects in the target community) as well as project factors (e.g., team capacity, budget, time constraints), as suggested by Berti et al. (2016).

This step of the TOPSIS method is the most subjective part. The goal is to be as objective as possible. For instance, to make an assessment of the current context in a country, a look at the available data on food and nutrition security might help. We chose four food security dimensions (i.e., food availability, food access, food utilization, and stability). Data on indicators from the four dimensions (from 2000 to present) for the Bolivian and Laotian contexts were retrieved from FAOSTAT (2021).

A Mann-Kendall Trend Test, which is monotonic, non-parametric and can be used with a minimum of 4 samples, was performed on the data from the food security indicators. Based on the trends, a weight was given to each category of NSA indicators (i.e., diet quality, on-farm availability, food environment in markets, income, women's empowerment, nutrition education, care practices, natural resources management practices, and nutritional status). The weighted normalized decision matrix was built by multiplying the normalized scores r_{ai} by their corresponding weights w_i:

$$v_{ai}=w_i \cdot r_{ai} \tag{2}$$

5.3.4.3 Ideal and anti-ideal virtual actions

The weighted scores were used to compare each action to an ideal (zenith) and anti-ideal (or negative idea) virtual action. This was done by collecting the best and worst performances on each criterion of the weighted normalized decision matrix. For the ideal action, we have

$$A^{+} = (v_1^{+}, \dots, v_m^{+}) \tag{3}$$

and for the anti-ideal action:

$$A^{-} = (v_1^{-}, \dots, v_m^{-}) \tag{4}$$

where v_i^{+} = max(v_{ai}) when criterion i was to be maximized and v_i^{-} = min(v_{ai}) when criterion i was to be minimized.

5.3.4.4 Distance for each action to the ideal and anti-ideal actions

To calculate the distance for each action to the ideal one (d_a^{+}) and the distance for each action to the anti-ideal one (d_a^{-}), the Euclidian value was used with the following equations:

$$d_a^{+} = \sqrt{\textstyle\sum_i (v_i^{*} - v_{ai})^2}\,,\ a = 1, \dots, m \tag{5}$$

$$d_a^{-} = \sqrt{\textstyle\sum_i (v_i^{-} - v_{ai})^2}\,,\ a = 1, \dots, m \tag{6}$$

5.3.4.5 Relative closeness coefficient

Finally, the relative closeness coefficient was assessed as follows:

$$C_a = \frac{d_a^{-}}{d_a^{+} + d_a^{-}} \tag{7}$$

The closeness coefficient is always between 0 and 1, where one is the preferred action. If an action is closer to the ideal than the anti-ideal, then C_a approaches 1, whereas if an action is closer to the anti-ideal than to the ideal, C_a approaches 0. By doing this, it was possible to rank the types of NSA interventions from the highest to the lowest C_a values.

5.4 Results and discussion

5.4.1 Weights of normalized values

As mentioned above, weighting the normalized values is the most subjective step of the process in the TOPSIS methodology. To do that, the food security context of Bolivia was analyzed, using indicators from four dimensions (availability, access, utilization, and stability). Data was retrieved from FAOSTAT (2021). The food security contexts of Laos and Ethiopia were also analyzed, but the plans of implementing projects for communities in those countries were set for later.

5.4.1.1 Food availability

Food availability refers to the availability of food in sufficient quantities and proper quality and safety, supplied via domestic production or imports (Mockshell and Villarino, 2019). Therefore, dietary energy supply adequacy, value of food production, protein supply, and supply of protein of animal origin were the indicators to measure food availability.

As seen in Figure 5.1a, both Bolivia and Laos reached in 2016 a food production of about 350 I$ per capita, being Laos the one that increased at a higher rate. Ethiopia, on the other hand, has a peak of about 113 I$. These increases were reflected in the average dietary energy supply adequacy: in the year 2000, it was about 95% in Laos and Bolivia; by the year 2022, the energy supply adequacy was about 104% for Bolivia, about 116% for Laos, and 112% in Ethiopia (Figure 5.1b), which means that, in average, these populations are consuming more calories than they need.

To grasp an idea about where these calories come from, the general protein supply (Figure 5.1c) and the supply of protein of animal origin (Figure 5.1d) were analyzed. It was found that the protein consumption in the three countries was between 50 and 57 g/cap/day in 2000. There were gradual increases in the three countries, reaching a value of about 75 g/cap/day in 2020 (Figure 5.1c). However, the protein consumption of animal origin was significantly higher in Bolivia (Figure 5.1d). This can be attributed to the fact that, despite Laotians eating fish and meat, they consume less milk and dairy products (Jeong et al., 2021). Regarding Ethiopia, the majority of energy intake comes from cereals, with on average only 3% of energy from meat (Hemler et al., 2022). Kraft et al. (2018) characterized and compared dietary profiles of 2 neighboring subsistence populations in Bolivia who vary in market integration.

5.4.1.2 Food access

Food access examines the individuals' access to suitable resources for acquiring appropriate food for a nutritious diet (FAO, 2012). The increasing global population and climate change are expected to affect food prices, which, in turn, will impact the household's income, food access and diet diversity (Mockshell and Villarino, 2019). Therefore, gross domestic product per capita and the percent of undernourishment prevalence were reported as indicators of food access.

Figure 5.2a, the gross domestic product per capita of Bolivia almost doubled the one from Laos in 2000. The gap, however, became narrower over time, meaning that the increase rate in Laos was higher. Ethiopia, however, was the country with the lower increase in this aspect. The gross domestic product per capita can be interpreted as purchasing power equivalent. The prevalence of undernourishment, on the other hand, indicates the depth of the food deficit and prevalence of food inadequacy. The prevalence of undernourishment in Laos was about 31.4%, while about 27.8% in Bolivia, during the year 2000 (Figure 5.2b). These values, however, have been abating over the years to 19.4% in Bolivia and 4.7% in Laos. Ethiopia shows a significant decrease, from 46.7% in 2000 to 21.9% in 2022. Based on the observed increasing values of the gross domestic product per capita and the decreasing values of prevalence of undernourishment in the three countries, it is fair to say that, over the years, people have more and more income for food access.

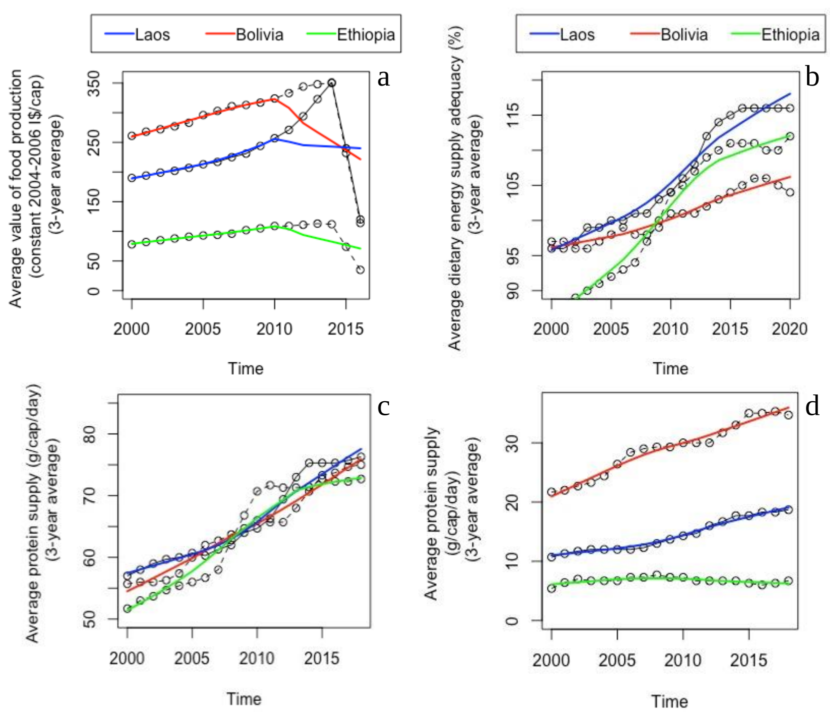

Figure 5.1 Mann-Kendall trend tests for the indicators that measure food availability: a) average value of food production, b) average energy supply adequacy, c) average protein supply, and d) average supply of protein of animal origin.

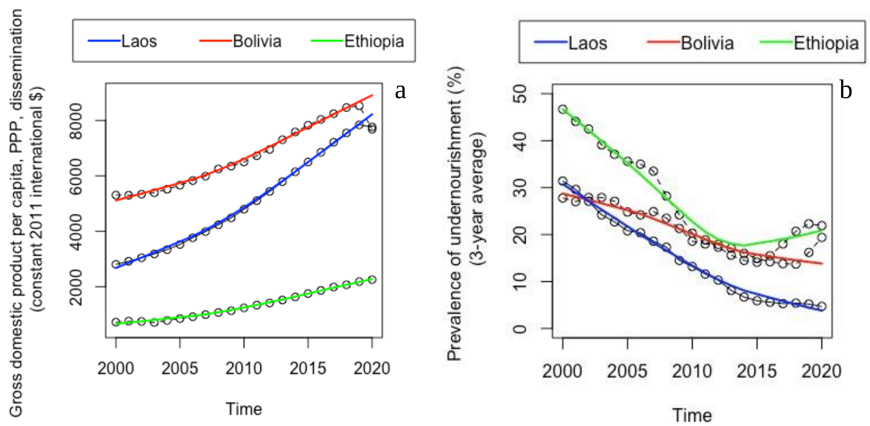

Figure 5.2 Mann-Kendall trend tests for the indicators that measure food access: a) gross domestic product per capita, and b) prevalence of undernourishment.

5.4.1.3 Food utilization

Similarly to food access, food utilization gives an idea of the individuals' access to adequate resources to obtain food for a nutritious diet (FAO, 2012). Among these resources, we took into account water and sanitation services, since clean water is relevant when it comes to prevent infections and deseases.

Figure 5.3a shows the increasing trend of the percentage of population using at least basic drinking water services from the year 2000 to 2020. That percentage has increased at an almost constant rate in the three countries (at a higher rate in Laos): from about 80% to 93.4% in Bolivia, from about 46.1% to approximately 85.2% in Laos, and from 18.1% to 49.6% in Ethiopia. The increasing rate of people using at least basic sanitation services was also higher in Laos (Figure 5.3b): the percentage has almost doubled in Bolivia, from 34.9% to 65.8%, and it has increased from about 28.2% to almost 79.5% in the same period in Laos. Ethiopia, on the other hand, although it has increased, the percentage is still low (8.9% in 2020).

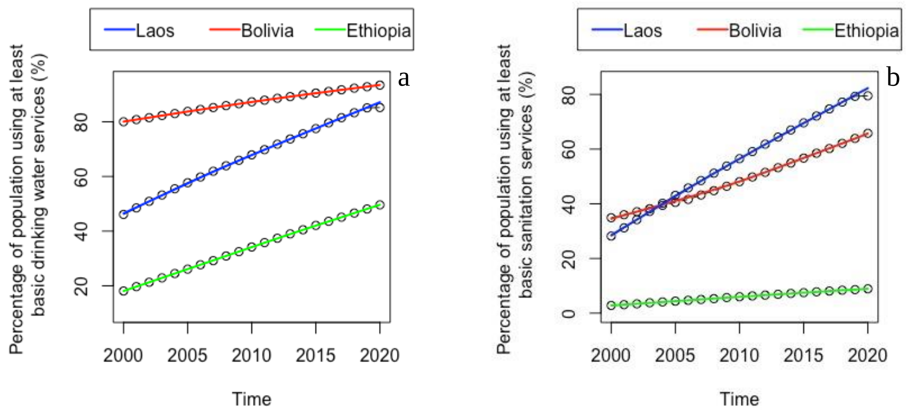

Figure 5.3 Mann-Kendall trend tests for a) percentage of population using at least basic drinking water services, and b) percentage of population using at least basic sanitation services. Both of these indicators are some of the measures of food utilization.

Anthropometric measures are indicators that assess the nutritional status. Stunting (low height-for-age) and overweight (high weight-for-height) of children under 5 years of age were considered for our analysis. As seen in Figure 5.4a, stunting tends to decrease over the years in Bolivia, from 32.9% in 2000 to 11.1% in 2022. A similar decreasing rate can be observed in Laos, but from 48.7% to 27.7%, while in Ethiopia it goes from 57% to 34.4%. Regarding overweight affecting children under 5 years of age, Bolivia is the country with the biggest percentage, with an almost constant 9%, followed by Laos (4% in 2022) and Ethipia (2% in 2022). (Figure 5.4b). The low percentage in Ethiopia should not be overlooked. The prevalence of obesity in adults was also analyzed, Figure 5.4d shows that it has been increasing at a constant rate in Bolivia, from 13.2% in 2000 to 20.2% in 2016; from 1.7% to 5.3% in Laos; and from 1.9% to 4.5% in Ethiopia in the same period.

Another way to assess the nutritional status of a population is by using biochemical measures. In this case, the prevalence of anemia among women of reproductive age and among children under 5 years of age was considered. Figure 5.4c shows how the population of children suffering from anemia has abated in the three countries from the year 2000 to 2019: from 57% to 36.9% in Bolivia, from 50.2% to 41.4% in Laos, and from 68.5% to 52.1% in Ethiopia. Regarding the Bolivian female population (Figure 5.4e), prevalace of anemia abated in the same period, from 33.1% to 24.4%. A similar decrease is observed in the Ethiopian female population (from 33% to 23.9%). The problem in Laos, however, is worse: the lowest percentage of anemia among women of reproductive age was 36.2% in 2011, but it has increased to 39.5% in 2019.

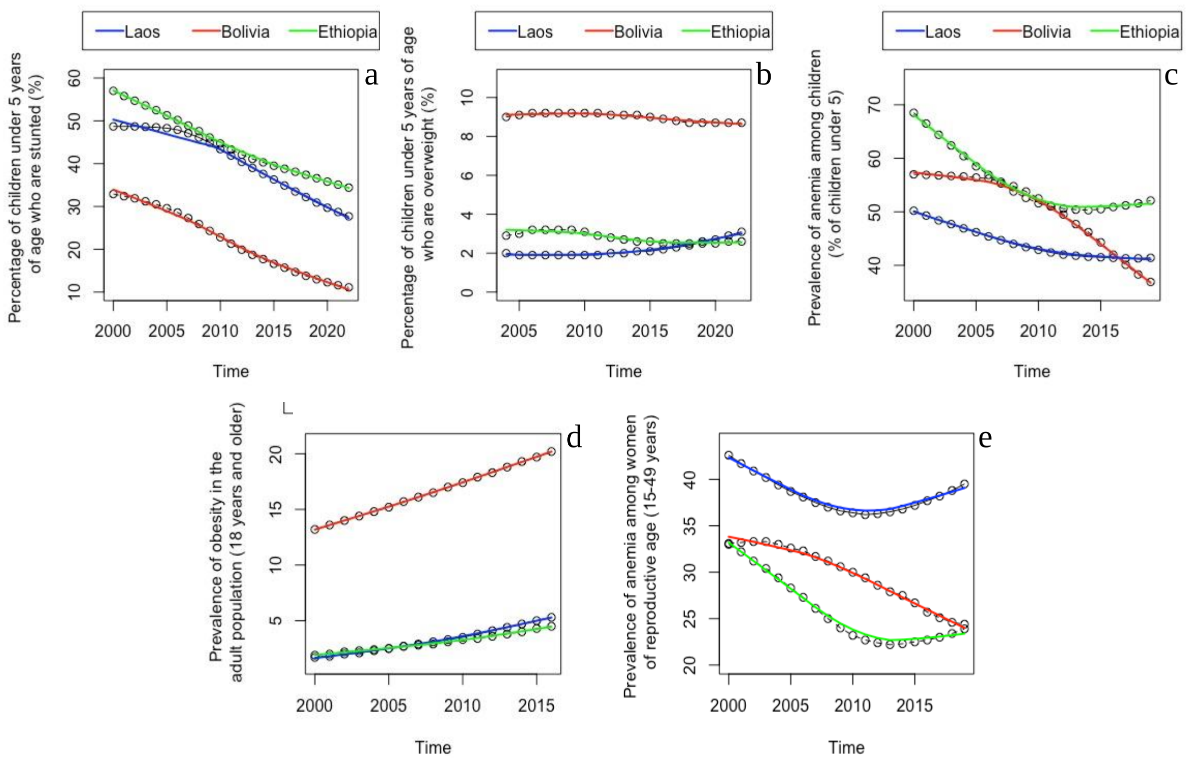

Figure 5.4 Mann-Kendall trend tests for indicators that measure food utilization: percentages of children under 5 years of age who are affected by a) stunting, b) overweight, and c) anemia. For adults, there are d) the prevalence of obesity, and e) the prevalence of anemia among women of reproductive age (15-49 years).

5.4.1.4 Food stability

To assess the food stability, we used the indicators shown in Figure 5.5. Food stability has to do with the household's access to nutritious food of high quality at all times (FAO, 2012). As observed by Mockshell and Villarino (2019), a way to guarantee food stability in rural areas is by promoting the local food production to develop local markets. By doing this, the agricultural value chain could be shortened, and the food waste could be reduced.

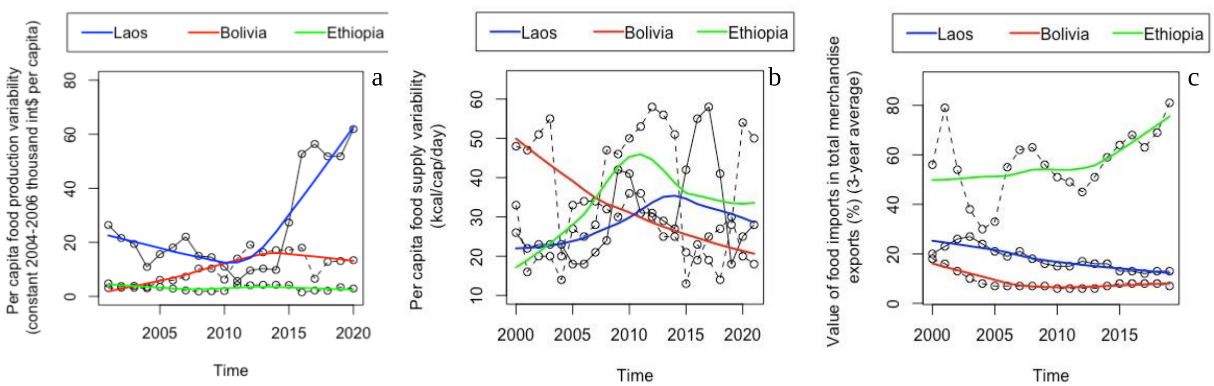

Figure 5.5 Mann-Kendall trend tests for indicators that measure food stability: a) per capita food production variability, b) per capita food supply variability, and c) value of food imports in total merchandise exports.

The per capita food production variability corresponds to the variability of the "food net per capita production value in 2014-2016 constant I$. As seen in Figure 5.5a the Bolivian food production variability has an increasing trend from 3.1 I$ in 2001 to 13.4 I$ in 2020, which is a negative tendency because the lower the variability the better. The Laotian food production variability, on the other hand, has a decreasing trend from 26.4 I$ in 2001 to 5.7 I$ in 2011, rising to 61.9 I$ in 2020. The Ethiopian food production variability has been relatively low, from 4.8 I$ in 2001 to 2.9% in 2020.

The Bolivian food supply variability abates from 48 kcal/capita/day in 2000 to 18 kcal/capita/day in 2021; the contrary happens in Laos, where it increases exponentially from 26 kcal/capita/day in 2000 to 42 kcal/capita/day in 2009, and then decreasing to 28 kcal/capita/day in 2021; while the Ethiopian food supply variability reaches a maximum of 58 kcal/capita/ day in 2012 with a tendency to decrease afterwards (Figure 5.5b) The decrease observed in the percentage value of food imports in total merchandise exports in Bolivia and Laos (Figure 5.5c) is a positive tendency, and it is consistent with the rising trend in the average value of food production. However, even when the Ethiopian average value of food production increases as well, the value of food imports shows an increasing trend, going from 56% in 2000 to 81% in 2019.

5.4.1.5 Assigning the weights to the categories of NSA indicators for the TOPSIS (for the Bolivian context only)

There are 10 categories into which FAO (2016) fits the indicators to measure the impact of NSA interventions. In order to assign weights to each category of NSA indicators, as mentioned above, the Bolivian context was considered, analyzing the indicators of food and nutrition insecurity.

As previously discussed, the food production has been increasing over the years, and the trend shows that it will continue increasing, as well as the rest of the food availability indicators. The gross domestic product per capita and the prevalence of undernourishment are the indicators for food access, and we see positive tendencies in both of them. It can also be seen that the per capita food supply variability tends to decrease over the years, which means that food stability keeps getting better. From these data, we can assume that there is not food scarcity in farms, households or markets, and that people have more than decent purchasing power to buy food. Therefore, implementing NSA interventions to generate income for nutrition or to improve food access, on-farm availability, and food environment in markets might not be as relevant.

By looking at the food utilization indicators, it is observed that stunting in Bolivia is an issue that becomes less and less relevant over the years. However, from 2008 to 2016, wasting increased. Overweight in children under 5 years of age, from 2012 to 2022, also increased. The prevalence of obesity in adults has been rising and it will continue to do so, based on the observed trend. In can be deduced that, despite the fact that energy needs are met, the food choices are not the most appropriate ones. Therefore, NSA interventions that aim to impact nutrition education, diet quality, and care practices are important. Even when the prevalence of anemia among women of reproductive age is decreasing, it is still significant. Hence, impacts of NSA interventions on the nutritional status should also be measured.

5.4.2 Output of TOPSIS (ranked interventions for the Bolivian context)

After answering the questionnaire, by using the TOPSIS method, two ranked lists were obtained: NSA interventions and NSA indicators. The ranked list of NSA interventions takes into account not only the answers but also the weights that were assigned to each category of NSA indicators.

The top NSA type of intervention, with a closeness value of 0.6157 (Table 5.5) was "Nutrition education and behavior change communication (BCC)", from the category "Consumer demand, food preparation and preferences". This type of interventions includes a wide variety of educational strategies to achieve long-lasting improvements in diets and eating habits within the target population. There are numerous studies that have performed this type of interventions in different countries (Bernet et al., 2018; Bonatti et al., 2018; Bostedt et al., 2016; Busse et al., 2018; Dangura and Gebremedhin, 2017; de Bruyn et al., 2019; Fernandes et al., 2016; Gebremedhin et al., 2017; Haghparast-Bidgoli et al., 2019; Heckert et al., 2019; Kadiyala et al., 2018; Marquis et al., 2018; Michaux et al., 2019; Nordhagen et al., 2019b; Nordhagen and Klemm, 2018; Ogutu et al., 2019; Olney et al., 2015; Port et al., 2017; Rosenberg et al., 2018; Rukmani et al., 2019; Schreinemachers et al., 2017a, 2017b; Shrestha et al., 2020; Verbowski et al., 2018). Shrestha et al., (2020), for example, designed a program in which children in grades 1-3 received nutrition-sensitive literacy promoting healthy food and hygiene behavior. They developed teaching material and they also trained the teachers on how to use such material. Agricultural training may help improve the food production, but it is not enough to guarantee the consumption of nutritious foods. As stated by Ogutu et al. (2019), combining agricultural and nutritional training in agricultural extension approaches may be a feasible approach. Therefore, it might be better if not only one type of intervention is performed in the target community.

Table 5.5 Ranked NSA types of interventions based on the closeness value from the TOPSIS methodology for the Bolivian context.

Category	**Type of NSA intervention**	**Closeness value**
Consumer demand, food preparation and preferences	Nutrition education and behavior change communication	0.6157
Food production	Nutrition-sensitive livestock and fisheries	0.5921
Food production	Diversification and sustainable intensification of agricultural production	0.5456

Food production	Biodiversity for food and nutrition	0.4199
Cross-cutting issues	Nutrition-sensitive value chains	0.4013
Food production	Urban and peri-urban agriculture	0.4012
Cross-cutting issues	Women's empowerment and gender equality	0.3882
Food production	Biofortification	0.3125
Consumer demand, food preparation and preferences	Income generation for nutrition	0.2757
Cross-cutting issues	Food quality, safety, and hygiene	0.2732
Food processing	Food fortification	0.2303
Food trade and marketing	Food labeling	0.2197
Food trade and marketing	Trade for nutrition	0.2130
Food trade and marketing	Food price policies for promoting healthy diets	0.2070
Food processing	Nutrition-sensitive post-harvest handling, storage, and processing	0.2040
Consumer demand, food preparation and preferences	School food and nutrition	0.2036
Consumer demand, food preparation and preferences	Nutrition-sensitive social protection	0.1979
Cross-cutting issues	Food loss and waste: prevention, reduction, and management	0.1934
Food trade and marketing	Food marketing and advertising practices	0.1846
Consumer demand, food preparation and preferences	Nutrition-sensitive humanitarian food assistance	0.1709

As seen in Table 5.5, the next top NSA interventions belong to the category of "Food production": "Nutrition-sensitive livestock and fisheries" (closeness value = 0.5921) and "Diversification and sustainable intensification of agricultural production" (closeness value =

0.5456). The livestock sector comprises different types of livelihoods and activities that range from animal rearing (e.g., cattle rearing) to homestead animal rearing (e.g., poultry rearing); and the fishery sector refers to both wild capture and aquaculture, including intensive to non-fed extensive fish farming (FAO, 2017). Dumas et al. (2018) performed an NSA intervention in which smallholder farmers were recruited as "egg producers" and were trained in hen health, biosecurity, food safety, and business management, finding a significant increase in household acquisition of eggs, particularly among households located closest to the egg production centers, and when egg production was high. Verbowski et al. (2018) selected 90 villages and assigned them to one of three treatments: diversified home gardens, diversified home gardens plus aquaculture (small fishponds) or control; compared to control, there were higher intakes of zinc and Vitamin A in the villages with home gardens, and higher intakes of iron, Vitamin A, and riboflavin in villages that included aquaculture. The NSA interventions performed by Verbowski et al. (2018) included education on hygiene and optimal nutrition for women and optimal infant and young child feeding practices, among other topics. They followed a multi-pathway approach. By doing so, chances of having an impact on nutritional status indicators are higher.

The aim of TOPSIS in this study, as stated before, is to determine which NSA interventions are the most suitable for a specific population based on its context. The user that answers the questionnaire will make a decision on which NSA intervention(s) (from the ensuing ranked list) to perform. The next step is to select a pathway to, finally, know what NSA indicators should be used to measure the impact (positive or negative).

5.4.3 Ranked indicators based on accumulated points

When looking at the ranked list of NSA indicators Table 5.6, it is not a surprise to see, at the top, "Changes in specific behaviors promoted about food safety" and "Nutrition and food safety-related knowledge", both from the category "Nutrition and food safety knowledge and norms". These indicators depend on the nature of the NSA intervention, and they vary from project to project. Shrestha et al. (2020) used a hygiene practice score, which was a test with multiple choice questions for children in grades 1-5, and a fruit and vegetable knowledge score; using photos, they also designed nutrition and hygiene knowledge, fruit and vegetable knowledge, and knowledge of healthier snacks.

Table 5.6 Ranked list of NSA indicators, based on the responses from the questionnaire, given by somebody planning to design an intervention in a Bolivian community.

Category	**Indicator**	**Value***
Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	0.7444
Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	0.6188
Care practices	Breastfeeding indicators	0.5404
Care practices	Minimum Meal Frequency	0.5316
Natural resource management practices, health, and sanitation environment	Sustainability of water availability and water use efficiency measures	0.5131
Diet quality - Individual level	Quantitative nutrient intakes	0.4893
Care practices	Minimum Acceptable Diet (MAD)	0.4882
Natural resource management practices, health, and sanitation environment	Contamination from water or environment in the food supply	0.4814
Diet quality - Individual level	Vitamin A-rich food consumption	0.4803
Diet quality - Individual level	Iron-rich food consumption	0.4759
Diet quality - Individual level	Individual Dietary Diversity Score (IDDS)	0.4734

Diet quality - Individual level	Consumption of specific target foods	0.4698
Diet quality - Individual level	MDD-W (Minimum Dietary Diversity – women of reproductive age)	0.4621
Natural resource management practices, health, and sanitation environment	Access to an improved drinking water source	0.4593
Diet quality - Individual level	The proportion of the diet consisting of processed/ultra-processed foods	0.4277
Diet quality - Individual level	Consumption of 400g fruits and vegetables per day	0.4161
Diet quality - Individual level	Unique Food Items/ Dietary variety	0.4124
Diet quality - Individual level	Minimum Dietary Diversity – Young children	0.3794
Natural resource management practices, health, and sanitation environment	Presence of animals in/ near household	0.3667
Natural resource management practices, health, and sanitation environment	Nutrition indicators for biodiversity	0.3598
Nutritional status	Vitamin A status	0.3389
Nutritional status	Iron status	0.3185
Nutritional status	Maternal weight/BMI	0.3040
Nutritional status	Anemia	0.2908
Women's empowerment	Qualitative process to understand equity, time use, and income control	0.2853
Women's empowerment	Women's time use and labor	0.2853
Nutritional status	Underweight	0.2843
Women's empowerment	Women's Empowerment in Agriculture Index (WEAI)	0.2731
Nutritional status	Stunting	0.2706
Women's empowerment	Women's control of income	0.2675
Nutritional status	Wasting	0.2661
Women's empowerment	Asset ownership by gender	0.2596
Food access - Household level	Food Insecurity Experience Scale (FIES)	0.0873

Food access - Household level	Food Consumption Score (FCS)	0.0844
Food access - Household level	Household Hunger Scale (HHS)	0.0821
Food environment in markets	Availability of specific foods in markets	0.0738
Income	Household asset index	0.0734
Income	Wealth indices/poverty levels	0.0731
Food environment in markets	Prices of particular foods in markets	0.0721
Food environment in markets	Cost of a healthy diet	0.0717
Food access - Household level	Escala Latinoamericana y Caribeña de Seguridad Alimentaria (ELCSA)	0.0717
Food access - Household level	Household Dietary Diversity Score (HDDS)	0.0713
On-farm availability, diversity and safety of foods	Implementation of good agricultural practices	0.0711
Food environment in markets	Food prices	0.0711
Income	Sales of agricultural products	0.0703
On-farm availability, diversity and safety of foods	Grain loss	0.0695
On-farm availability, diversity and safety of foods	Functional diversity index	0.0686
Food environment in markets	Functional diversity index	0.0685
Food access - Household level	Household Food Insecurity Access Scale (HFIAS)	0.0667
On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	0.0640
Income	Income or consumption	0.0640
Food environment in markets	Food loss in the supply chain	0.0625
Food access - Household level	Coping Strategies Index (CSI)	0.0606
Food access - Household level	Months of Adequate Household Food Provisioning (MAHFP)	0.0588
On-farm availability, diversity and safety	Diversity of foods produced on-farm	0.0573

of foods		
On-farm availability, diversity and safety of foods	The proportion of staple crop production that is biofortified	0.0538
Food environment in markets	Indicators of food safety within the food environment	0.0408

*The value reported represents the points that each indicator accumulated when answering the questions from the questionnaire, multiplied by the weight from each category.

Verbowski et al. (2018) used 24H to collect data on the food and beverages consumed in a 24 h period, the food preparation methods, and the portion sizes and recipes. By using different databases, they gathered data on food composition in order to quantify the intakes of vitamins (e.g., Vitamin A, riboflavin), and micronutrients (e.g., zinc, iron). They also collected data on anthropometric measures (i.e., stunting, wasting, underweight for children and maternal body mass index for women). They, however, did not use any indicators to measure the impact on the nutrition education. When it comes to the design of NSA interventions, one of the gaps is the full measurement of the full pathway of change from agricultural inputs and practices to nutrition outcomes in current research (Herforth and Ballard, 2016).

If a manager plans to perform a project with NSA interventions that include home gardens and nutrition education activities like Verbowski et al. (2018), and they intend to improve the nutritional status of their target population, it would be expected that they select indicators to measure the full pathway (Figure 5.6): availability, diversity and safety of foods (e.g., implementation of good agricultural practices); food access (e.g., household dietary diversity score); nutrition knowledge (e.g., nutrition and hygiene practice score); care practices (e.g., minimum meal frequency); diet quality (e.g., quantitative nutrient intakes) and, of course, nutritional status (e.g., stunting, wasting).

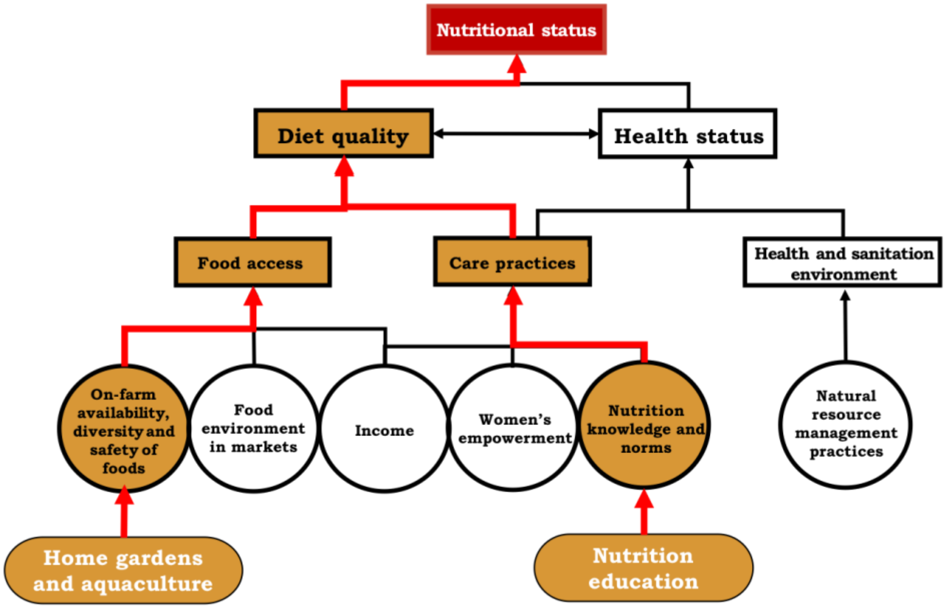

Figure 5.6 A sample of an NSA project that includes two types of interventions: a) food production (home gardens and aquaculture), and b) nutrition education. The pathway that may be followed to improve the nutritional status is highlighted in orange.

The point of having a ranked list of NSA indicators is to help the project manager make a well-informed decision regarding the most suitable metrics and indicators to measure the impact of the type(s) of intervention(s) and pathway(s) that they intend to follow. This methodology can be transformed into an App in which the user only has to answer a set of questions and make several selections.

The smartphone application would offer not only the ranked lists of NSA interventions and indicators, but also the data collection tools and materials (e.g., 24H, FR, FFQ) as well as the training material to learn how to collect the required data (refer to Figure 5.7).

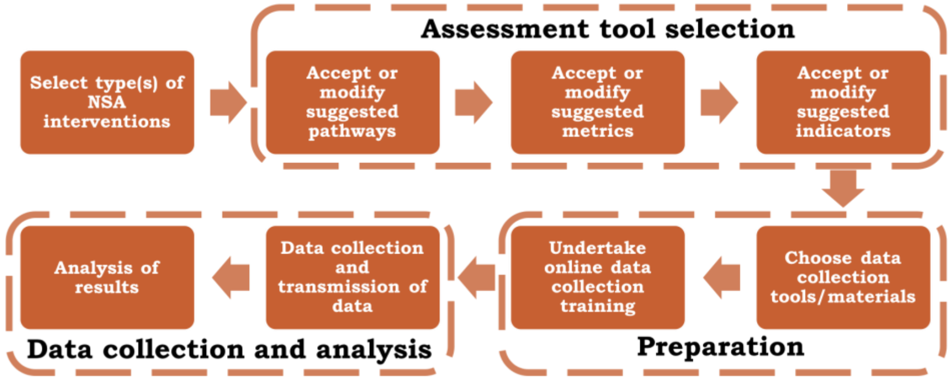

Figure 5.7 Framework for the suggested development of the smartphone application.

5.5 Conclusion

Among the current gaps in NSA projects, we can mention that each investment needs to be analyzed ex ante for a clear theory of change and, depending on the context of the target population, the most appropriate type of NSA interventions will vary. There are many indicators that may be used to measure the impact (positive or negative) of NSA interventions, and it can be difficult to track what each of them does and does not reflect. This is why mixed results have been reported from NSA studies: sometimes the magnitude of the NSA intervention changes depending on the indicators that are used to measure it.

This work is expected to fill the current gaps when it comes to designing NSA interventions. The ensuing algorithm will not only offer the most suitable types of NSA interventions and indicators for a population based on its context, but also the metrics, the data collecting tools and everything that is required to gather the proper information to measure the impact in the full pathway of change from agricultural inputs and practices to nutrition outcomes. In other words, the tool is expected to assess the baseline agriculture-nutrition nexus, and to evaluate any changes after the intervention(s) take(s) place.

CONNECTING TEXT

In the previous chapter, we discussed the challenges of using the appropriate metrics and indicators when measuring each step of the pathway towards improving the nutritional status of a population. An algorithm was developed to identify both the types of NSA interventions and indicators that are more suitable given the context of the community where the project is to take place and the priorities of the people designing the project. One weakness that we found, however, was the subjectivity associated with the step of assigning weights when building the weighted normalized decision matrix. Chapter VI, therefore, will be focused on describing how to reduce such subjectivity mathematically, by applying the Entropy method, as well as on validating the algorithm with published NSA studies.

VI. THE ENTROPY-BASED TOPSIS METHOD TO HELP DESIGN NSA INTERVENTIONS, AND ITS VALIDATION

6.1 Abstract

There is a need to turn the labor of designing nutrition-sensitive agriculture interventions (NSA) into a simpler task. Therefore, an algorithm was developed, using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). This method has a relatively low input effort from the user, and it offers a complete list of the alternatives, ranked from the most to the least relevant one based on a closeness value. One identified weakness was that assigning weights for the normalized decision matrix can be a subjective part of the process. In this study, the entropy method (EM) was used to determine the weights objectively in a mathematical way. Besides, we extracted data from published NSA studies (i.e., duration of the project, region where the project took place, food security context, targeted segments of the population, theory of change, indicators used to measure outcomes and impacts, and the types of NSA interventions chosen to be implemented) to test our developed entropy-based TOPSIS algorithm, applying the Kendall's correlation coefficient (τ) to validate. In almost all cases, all the types of NSA interventions that the authors chose were present in the top 5 of the ranked lists (τ values ranged from 0.9263 to 0.9895), making this tool a promising one for NSA intervention designers, managers and stakeholders. The algorithm can improve its performance constantly by feeding it with more data from successful projects.

Keywords: automation; machine learning; multi-criteria decision analysis (MCDA)

6.2 Introduction

Given the complexity in the task of designing nutrition-sensitive agriculture (NSA) interventions (Mayorga-Martínez et al., 2023), a multi-criteria decision analysis (MCDA) method was used to help make suitable decisions regarding the selection of intervention types. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was chosen to build the algorithm because, as previously explained, it offers a complete list of the possible solutions, ranked from the most to the least relevant based on a closeness value, and because the method requires a relatively low input effort from the user. With the developed algorithm, the user as well can be guided through the different pathways towards improving the nutritional status. And, based on what pathway they end up choosing, the algorithm offers a list of the suitable indicators to measure the outcomes and the impacts along the way.

When using TOPSIS, determining the attribute weights is a required step. The weights can be determined either subjectively (e.g., considering the priorities of the decision maker), or objectively, using other mechanistic methods. In the previous chapter, the weights were assigned based on the results from the analysis of the four dimensions of food security from the regions. This, however, represents a weakness in the algorithm, because there is still some subjectivity in the process. Therefore, there is a need to apply a mathematical technique to assign such weights. There are numerous available methods for this purpose, such as analytic hierarchy process (AHP) (Saaty, 1988), entropy method (EM) (Hwang and Yoon, 1981), deviation maximization method, best-worst method (Rezaei, 2015), and variation coefficient method (Liu et al., 2018). The EM calculates the attribute weights based on the diversity of attribute data among the alternatives (Chen, 2019). Compared with the subjective weighting method represented by AHP, the EM is simple in calculation and does not require the subjective preference; it only requires objective data

(Chen, 2021). Besides, according to the current application status of TOPSIS, the EM is frequently used as the weight determination method for TOPSIS (Behzadian et al., 2012). In information theory, the entropy by Shannon can be used to determine the disorder degree and its utility in system information. The smaller the entropy, the smaller the disorder degree.

60 NSA studies, published from 2010 to April 2021 in peer-reviewed articles, were used to train the developed algorithm. However, it had not been validated, which was another weakness. Therefore, the objectives of this work were: 1) to test the EM with TOPSIS to reduce the subjectivity when assigning the attribute weights, and 2) to validate the algorithm using recent NSA studies that were different from the ones that were used to train it.

6.3 Materials and Methods

6.3.1 The Entropy Method

The entropy method was adapted from (Li et al., 2011). Supposing that there are *m* types of NSA interventions and *n* pieces of NSA indicators in the indicator system, x_{ij} is the j^{th} indicator's value in the i^{th} type of intervention. To eliminate the influence of indicator dimension on incommensurability, it is necessary to standardize indicators using the equations of relative optimum membership degree.

To the benefit indicators, the attribute value of the j^{th} indicator in the i^{th} type of NSA intervention can be transformed by:

$$r'_{ij} = \frac{x_{ij}}{max_j\, x_{ij}}, (i = 1,\ldots,m;\ j = 1,\ldots,n) \qquad (1)$$

To the cost indicators, the attribute value of the j^{th} indicator in the i^{th} type of NSA intervention can be transformed by:

$$r'_{ij} = \frac{\min_j x_{ij}}{x_{ij}}, \min_j \neq 0, (i = 1,\ldots,m;\ j = 1,\ldots,n) \qquad (2)$$

After standardization of indicators, the standardized indicator matrix is $R' = [r_{ij}]_{mxn}$.

The next step would be the calculation of the indicator's entropy. Based on the definition of entropy, entropy of the j^{th} indicator is determined by:

$$H_j = \frac{\sum_{i=1}^{m} f_{ij} \ln f_{ij}}{\ln m}, (i = 1,\ldots,m; j = 1,\ldots,n) \quad (3)$$

wherein:

$$f_{ij} = \frac{r'_{ij}}{\sum_{i=1}^{m} r_{ij}}, (i = 1,\ldots,\mathrm{m}; j = 1,\ldots,n) \quad (4)$$

Finally, the indicator's entropy weight has to be calculated. Entropy weight of the j^{th} indicator is determined by:

$$w_j = \frac{1-H_j}{n-\sum_{j=1}^{n} H_j}, \sum_{j=1}^{n} w_j = 1 (j = 1, \ldots, n) \quad (5)$$

The ensuing *w* values were used to obtain the weighted decision matrix.

6.3.2 Validation

A literature review was done using the key words: "nutrition sensitive" AND ("agriculture" OR "food system*"). These are the same key words with which the 60 studies to train the algorithm were found. This time, however, 15 additional studies were selected to perform a validation. The obtained data from these studies included: a) the duration of the project, b) aspects of the food security context within the region (e.g., food availability, food utilization), c) the targeted segments of the population (e.g., pregnant or lactating women, children under 5 years of age), d) the Theory of Change (ToC) to determine the intended pathways towards improving the nutritional status (e.g., food access, diet quality, nutrition knowledge and norms), e) the indicators used to measure outcomes and impacts (e.g., MDD-W, HDDS,), and f) the suggested/implemented types of NSA interventions (e.g., nutrition education and behavior change communication, nutrition-sensitive livestock and fisheries, school food and nutrition). All this information was useful to answer the 97 questions from the questionnaire associated with the developed algorithm that uses the entropy-based TOPSIS method to rank the types of interventions from the most to the least relevant one.

6.3.3 Statistical analysis

The Kendall's correlation coefficient (τ) is a nonparametric test procedure. Thus, the data need not be normally distributed and the two variables need only have ordinal scale levels. The two variables for each comparison were: the NSA interventions sorted by the developed TOPSIS algorithm (x), and the NSA interventions prioritized by the authors (y). τ was calculated for each selected study as:

$$\tau = \frac{S}{n(n-1) * 0.5}$$

where S is the number of concordant pairs minus the number of discordant pairs, and n is the number of NSA interventions. The analyses were performed using RStudio (2023.06.2+561).

6.4. Results and Discussion

6.4.1 Weight attributes from using the Entropy Method (EM)

The frequency percentages (the frequency with which an indicator was used in each type of NSA interventions) were used to assign weights. The NSA indicators were grouped into the ten categories suggested by FAO: diet quality (C_1); food access (C_2); on-farm availability, diversity and safety of foods (C_3); food environment in markets (C_4); income (C_5); women's empowerment (C_6); nutrition and food safety knowledge and norms (C_7); care practices (C_8); natural resource management practices, health, and sanitation environment (C_9); and nutritional status (C_{10}), which includes anthropometric and biochemical measures. Table 6.1 shows the sums of the frequency percentages for each category.

Table 6.1 Accumulated frequency percentages of each category of indicators for each type of NSA intervention.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Diversification and sustainable intensification of agricultural production	0.79	0.47	0.31	0.25	0.39	0.26	0.05	0.10	0.20	0.30
Nutrition-sensitive livestock and fisheries	0.68	0.42	0.34	0.20	0.32	0.26	0.05	0.15	0.22	0.33
Biodiversity for food and nutrition	0.56	0.32	0.69	0.25	0.18	0.15	0.05	0.18	0.30	0.19
Biofortification	0.49	0.18	0.30	0.20	0.19	0.13	0.05	0.24	0.20	1.05
Urban and peri-urban agriculture	0.63	0.29	0.32	0.29	0.32	0.26	0.05	0.12	0.27	0.18
Nutrition-sensitive post-harvest handling, storage, and processing	0.55	0.26	0.45	0.54	0.22	0.26	0.05	0.08	0.37	0.18
Food fortification	0.44	0.20	0.28	0.25	0.20	0.13	0.05	0.24	0.20	1.05
Trade for nutrition	0.45	0.25	0.25	0.23	0.30	0.31	0.05	0.17	0.20	0.42
Food marketing and advertising practices	0.37	0.18	0.18	0.43	0.32	0.20	0.10	0.20	0.17	0.37
Food price policies for promoting healthy diets	0.45	0.46	0.16	0.63	0.33	0.15	0.05	0.15	0.13	0.20
Food labeling	0.39	0.18	0.28	0.35	0.15	0.13	0.40	0.18	0.13	0.33
Nutrition education and behavior change communication	0.94	0.37	0.21	0.25	0.36	0.34	0.10	0.15	0.20	0.47
Income generation for nutrition	0.43	0.51	0.15	0.67	0.50	0.33	0.05	0.12	0.17	0.18
Nutrition-sensitive social protection	0.39	0.59	0.15	0.41	0.53	0.29	0.05	0.20	0.20	0.18
School food and nutrition	0.53	0.42	0.40	0.34	0.16	0.17	0.40	0.18	0.15	0.18
Nutrition-sensitive humanitarian food assistance	0.28	0.69	0.15	0.33	0.28	0.13	0.05	0.10	0.15	0.34
Nutrition-sensitive value chains	0.53	0.27	0.23	0.34	0.34	0.25	0.05	0.17	0.25	0.32
Women's empowerment and gender equality	0.60	0.36	0.20	0.20	0.65	1.00	0.05	0.16	0.20	0.39
Food loss and waste: prevention, reduction, and management	0.25	0.46	0.55	0.53	0.15	0.16	0.10	0.08	0.67	0.18
Food quality, safety, and hygiene	0.28	0.18	0.45	0.36	0.15	0.14	0.20	0.08	0.66	0.21

According to the evaluation indexes, which are the benefit indexes or the cost indexes, standardization of indexes is calculated by (1) ~ (2) and shows as follows.

$$
R' = \begin{pmatrix}
0.08 & 0.07 & 0.05 & 0.04 & 0.07 & 0.05 & 0.03 & 0.03 & 0.04 & 0.04 \\
0.07 & 0.06 & 0.06 & 0.03 & 0.05 & 0.05 & 0.03 & 0.05 & 0.04 & 0.05 \\
0.06 & 0.05 & 0.11 & 0.04 & 0.03 & 0.03 & 0.03 & 0.06 & 0.06 & 0.03 \\
0.05 & 0.03 & 0.05 & 0.03 & 0.03 & 0.03 & 0.03 & 0.08 & 0.04 & 0.15 \\
0.06 & 0.04 & 0.05 & 0.04 & 0.05 & 0.05 & 0.03 & 0.04 & 0.05 & 0.03 \\
0.06 & 0.04 & 0.08 & 0.08 & 0.04 & 0.05 & 0.03 & 0.03 & 0.07 & 0.03 \\
0.04 & 0.03 & 0.05 & 0.04 & 0.03 & 0.03 & 0.03 & 0.08 & 0.04 & 0.15 \\
0.05 & 0.04 & 0.04 & 0.03 & 0.05 & 0.06 & 0.03 & 0.06 & 0.04 & 0.06 \\
0.04 & 0.03 & 0.03 & 0.06 & 0.05 & 0.04 & 0.05 & 0.07 & 0.03 & 0.05 \\
0.05 & 0.07 & 0.03 & 0.09 & 0.05 & 0.03 & 0.03 & 0.05 & 0.03 & 0.03 \\
0.04 & 0.03 & 0.05 & 0.05 & 0.03 & 0.03 & 0.20 & 0.06 & 0.03 & 0.05 \\
0.09 & 0.05 & 0.04 & 0.04 & 0.06 & 0.07 & 0.05 & 0.05 & 0.04 & 0.07 \\
0.04 & 0.07 & 0.03 & 0.10 & 0.08 & 0.07 & 0.03 & 0.04 & 0.03 & 0.03 \\
0.04 & 0.08 & 0.03 & 0.06 & 0.09 & 0.06 & 0.03 & 0.07 & 0.04 & 0.03 \\
0.05 & 0.06 & 0.07 & 0.05 & 0.03 & 0.03 & 0.20 & 0.06 & 0.03 & 0.03 \\
0.03 & 0.10 & 0.03 & 0.05 & 0.05 & 0.03 & 0.03 & 0.03 & 0.03 & 0.05 \\
0.05 & 0.04 & 0.04 & 0.05 & 0.06 & 0.05 & 0.03 & 0.06 & 0.05 & 0.05 \\
0.06 & 0.05 & 0.03 & 0.03 & 0.11 & 0.20 & 0.03 & 0.05 & 0.04 & 0.06 \\
0.02 & 0.07 & 0.09 & 0.08 & 0.03 & 0.03 & 0.05 & 0.03 & 0.13 & 0.03 \\
0.03 & 0.03 & 0.08 & 0.05 & 0.03 & 0.03 & 0.10 & 0.03 & 0.13 & 0.03
\end{pmatrix}
$$

Weights of the ten indicator categories were calculated by (3) ~ (5) and shown in Table 2. The advantage of using these weights to build the weighted normalized decision matrix is that the subjectivity from the user is reduced.

Table 6.2 Weights of indexes' categories.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
H	0.982	0.972	0.966	0.975	0.969	0.937	0.873	0.982	0.954	0.934
w	0.0399	0.0604	0.0741	0.0538	0.0685	0.1386	0.2792	0.0396	0.1011	0.1446

6.4.2 Validation of the entropy-based TOPSIS method to rank NSA interventions

Out of the 75 studies found with the key words: "nutrition sensitive" AND ("agriculture" OR "food system*"), 60 were used to train the TOPSIS algorithm, and 15 (Table 3) were used to validate.

Table 6.3 Nutrition-sensitive agriculture (NSA) studies from which data were used to validate the entropy-based TOPSIS.

Study	Duration	Region	Reported food security context	Targeted segments of the population	Theory of change	Indicators used	implemented types of NSA interventions
(Ambikapathi et al., 2021)	Years	Four regions in Ethiopia	The recent 'Fill the nutrient gap' report for Ethiopia revealed that a substantial proportion (>60%) of Ethiopian households cannot afford the minimum cost-nutritious diet, modelled for a five-member household that included nutritionally vulnerable groups like lactating women, adolescents and children under 2 years of age.	Women of reproductive age, children under 5 years of age	On-farm availability, food access, diet quality, natural resource management	MDD-W; CDDS; distance to market (min); HFIAS; HDDS; access to an improved water source; nutrition and safety-related knowlege; breastfeeding; household asset index	Introduction of chickens of improved breeds to households (NS livestock and fisheries); behavior change communication on women and children's nutrition, water, sanitation, hygiene, and women's empowerment (nutrition education and behavior change communication)
(Berti and Araujo-Cossio, 2017)	Years	21 rural communities in Bolivia	Diet dominated by tubers and grains, with fewer high-nutrient density foods, and low intake of fatty fewer high-nutrient density foods, and low intake of fatty foods. Diet of rural Andeans often inadequate: low intakes of micronutrients, including iron, zinc, vitamin A, riboflavin, vitamin B12 and folate, and very low intakes of dietary fat.	Children under 5 years of age, male and female adults older than 18	On-farm availability, diet quality, nutrition knowledge and norms, care practices	Consumption of specific target foods; quantitative nutrient intakes	Chicken-rearing for egg production (NS livestock and fisheries); training on family nutrition and emphasized the importance of a good diet, especially egg consumption, for the physical and mental development of children, and good breastfeeding practices (nutrition education and behavior change communication)
(Blakstad et al., 2019)	Months	Tanzania	Women and children often consume monotonous diets of poor nutritional value primarily because of physical or financial inaccessibility or low awareness of healthy foods.	Women of reproductive age, children under 10 years of age	On-farm availability, food access, diet quality; nutrition education and knowledge	MDD-W; changes in specific behaviors promoted (adoption of home gardens); wealth index; distance to market (km); diversity of foods produced on-farm	Home gardens (diversification and sustainable intensification of agricultural production); nutrition counsellilng and basic public health messages (nutrition education and behavior change communication)

(Daum et al., 2022)	Years	Zambia	The Eastern and Southern Provinces of Zambia ranks 113th out of 117 countries according to the Global Hunger Index. In Zambia, 37% of the population are food insecure, 40% of the children are stunted and nearly half of the population experiences seasonal hunger. Moreover, deficiencies of Vitamin A, B12, Folate, Iron, and Iodine are prevalent across Zambia.	Households	Natural resource management, nutrition knowledge and norms	Functional diversity index (edible weeds); contamination from water or environment in the food supply (due to herbicides) nutrition and food safety-related knowledge (about edible weeds and herbicides)	The role of weeds for diets (biodiversity for food and nutrition)
(Di Prima et al., 2022)	Years	A small community in Vietnam	households included 42% mildly food insecure, 39% moderately, and 6% severely. 43% children under 5 were underweight and 61% were stunted. The local diet generally consisted of rice, cassava leaves, wild vegetables, chili, and salt.	Children under 5 years of age	On-farm availability, food access, diet quality, nutrition knowledge and norms, care practices	Income or consumption; IDDS; HDDS	Homestead food production (diversification and sustainable intensification of agricultural production); training on detecting early malnourishment and nutrition counselling skills (nutrition education and behavior change communication); school meals supply (school food and nutrition)
(Kaminski et al., 2022)	Months	Luwingu District in northern Zambia	Most of the fish consumed by Zambians come from freshwater capture fisheries, not from aquaculture, and are eaten as dried and/or smoked products. Fish consumption is stratified along economic lines and poorer people tend to consume small, dried, cheap fish, while well-off people tend to consume large, fresh fish, such as farmed tilapia.	Children and pregnant or lactating women	On-farm availability, nutrition knowledge and norms, food access	Consumption of specific target foods (fish); quantitative nutrient intakes; wealth index	Pond polyculture (NS livestock and fisheries); training on pond management and human nutrition (nutrition education and behavior change communication)

(Port et al., 2017)	Years	Northern Senegal	In Senegal, the prevalence of anemia is extremely high, with 76% of children under-five years of age being anemic	Children under 5 years of age	Food environment, nutrition knowledge and norms, food access, care practices, diet quality, nutritional status	Ownership of assets at household; HFIAS; maternal knowledge; consumption of specific target groups (fortified yogurt); hemoglobin concentration; anemia prevaflence	Distribution of a micro-nutrient fortified yogurt (food fortirication); campaign focused on child nutrition (nutrition education and behavior change communication)
(Ma et al., 2021)	N/A	Quebec, Canadá	Low fruit and vegetable consumption impacts the economy, with some countries like Canada estimating the economic burden to be over CAD 3.3 billion each year, of which 30.5% is associated to direct healthcare costs	Members at grocery stores in Quebec	Food environment in markets, food access	Food expenditure share of vegetable type and of all vegetables (income or consumption); neighborhood socioeconomic and household characteristics as proxy for individual socioeconomic and household characteristics (wealth indexes)	The complexity of observed expenditure patterns points to a need for more specific vegetable consumption guidelines that include provisions by processing level (nutrition education and behavior change communication); food marketing and advertising practices; food price policies for promoting healthy diets

(Ojo et al., 2023)	Years	Kano and Oyo states of Nigeria	Nigeria contributes to the global burden of chronic undernutrition in children under 5 years of age. Smallholder pastoralists in Nigeria face: limited use of modern inputs and improved technologies; poor access to credit facilities; inadequate mechanization; poor farm-gate prices; and limited institutional and basic infrastructure, such as research and extension services. Specific to milk production: poor genetic composition of local cattle breed; poor feeding practices; archaic production practices; poor milk safety, hygiene, and sanitation practices; lack of cold chain infrastructure; and inadequate market access.	Children under 5 years of age, women of reproductive age	On-farm availability, income, nutrition education and behavior change communication, women's empowerment; natural resource management; food access; care practices; diet quality; health environment; nutritional status	Maternal weight/BMI; MUAC in children 6-59 months old; MDD-W; food expenditure; HHS; Household income; household asset index; access to improvedd dirnking water source; nutrition and food-related knowledge; women's decision power	Own consumption (NS livestock and fisheries); nutrition knowledge for women (nutrition education and behavior change communication); selling milk to processors to increase women's income (women's empowerment and gender equity); households training on soapmaking and the construction of handwashing facilities, to reduce barriers to optimal hygiene practices (food quality, safety, and hygiene)
(Saint Ville et al., 2022)	Years	Island of St. Kitts	Low levels of dietary diversity, high dependence on imported, energy-dense and ultra-processed foods lead the children from St. Kitt to suffer from overweight and obesity. Obese children are more likely to become obese adults with an increased risk of suffering from NCDs later in life.	6- to 12-year-old children	On-farm availability, food environment in markets, nutrition knowledge and norms, care practices, diet quality	Dietary and antrhopometric measures were taken from the children: quantitative nutrient intakes, overweight and obesity	Lunch meals delivered to schools (school food and nutrition); increasing local production of fruits and vegetables (diversification and sustainable intensification of agricultural production)

(Sharma et al., 2021b)	Years	Northern Laos	As per the Lao social indicator survey 2017, 33% of children under the age of five years are stunted, 21% are underweight, and 9% are wasted. The difference in stunting rates between the richest and poorest, and urban areas and rural areas are 40.9% and 21.2%, respectively. 40% of women of reproductive age are anemic. 88% of average calorie intake per capita comes from rice whereas there is less consumption of other foods such as meat, eggs, fats, and oils.	Children under 5 years of age, women of reproductive age	On-farm availability, food environment in markets, nutrition knowledge and norms, women's empowerment, care practices, diet quality	MDD-W; MCD-C; availability of specific foods on-farm; diversity of foods produced on-farm; nutrition and food safety-related knowledge; changes in specific behaviors promoted about food; breastfeeding indicators; MAHFP; MMF; asset index; distance to market (km)	Home gardens (diversification and sustainable intensification of agricultural production); training on rearing livestock (NS-livestock and fisheries); selling surplus agricultural products (income generation for nutrition); monthly cooking demonstrations, and counselling on optimal nutrition and WASH practices (nutrition education and behavior change communication); WASH infrastructural support (food quality, safety, and hygiene); increase women's participation in activities (women's empowerment and gender equity)
Sharma et al. 2021(Sharma et al., 2021a)	Years	Southern Bangladesh	The proportion of stunting, underweight and wasting among children less than five years of age is 31%, 22% and 8%, respectively. Besides, 40% of women of reproductive age are anemic, and a high proportion of pre-school aged children are deficient in vitamin A, zinc, vitamin D, iron, and suffer from anemia. The food system has traditionally focused on rice as the main staple crop.	Households, children under 5 years of age, pregnant or lactating women	On-farm availability, nutrition knowledge and norms, food access	Perceived effects on nutrition outcomes (what effects and how the effects or pathways) and the factors affecting implementation and sustainability (barriers and facilitators); underweight; stunting	Provision of training on improved technologies and inputs for horticulture (diversification and sustainable intensification of agricultural production); livestock and aquaculture (NS livestock and fisheries); demonstration of healthy and diverse cooking, and community-based food preservation and processing (nutrition education and behavior change communication); nutrition-specific components to increase the coverage and outreach of iron-folic acid supplementation for pregnant women and de-worming for children six to 23 months old (food fortification)

(Tizazu et al., 2022)	Years	Ethiopia	The recent 'Fill the nutrient gap' report for Ethiopia revealed that a substantial proportion (>60%) of Ethiopian households cannot afford the minimum cost-nutritious diet, modelled for a five-member household that included nutritionally vulnerable groups like lactating women, adolescents and children under 2 years of age.	Children under 5 years of age	On-farm availability, food access, nutrition knowledge and norms, food access, care practices, diet quality	MDD-C; MMF; MAD; Consumption of 400g fruits and vegetables per day; bottle feeding; wealth indices	Diversifying food supply (diversification and sustainable intensification of agricultural production); regulating the market of unhealthy foods (food price policies for promoting healthy diets); promoting minimal processing of perishables (nutrition-sensitive post-harvest handling, storage, and processing); nutrition education and behavior change communication; nutrition-sensitive social protection
(Vinceti et al., 2022)	Years	Burkina Faso	The flora of Burkina Faso has a large number of food plants, either growing spontaneously or cultivated, playing a critical role in the diets and income generation of the rural population. The various edible parts of plants are consumed in different ways: raw, cooked, or further processed. The plants used, as well as the recipes, vary considerably from one location to another due to differences in cultural background and plant species locally available.	Women of reproductive age	On-farm availability, food access, diet quality	MDD-W; nutiriton indicators for biodiversity	A methodology to select a portfolio of tree species that optimizes (i) availability of edible products through complementarity in seasonality, and (ii) diet diversity through complementarity in the food groups represented by the different edible products (biodiversity for food and nutrition)
(Warner et al., 2023)	Years	Rwanda	Despite solid economic growth and improved access to schooling and basic infrastructure, such as piped water, sanitation, and electricity, Rwanda is still struggling with high levels of malnutrition, especially child stunting. A 2012 cost of hunger study estimated that up to 11.5% of gross domestic product per year was lost due to undernutrition alone.	Children under 5 years of age, pregnant women	On-farm availability, food environment in markets, food access, nutrition knowledge and norms, care practices	Stunting; vitamin A-rich food consumption; hygienic disposal of children's stools (changes in specific behaviors promoted about food safety); iron-rich food consumption; iron status; vitamin A status; HDDS; FIES	Complementary feeding, including education (nutrition education and behavior change communication); supplementations of zinc, vitamin A, calcium and energy (food fortification)

Figure 6.1 shows the top 5 of NSA interventions for each selected study, arranged based on the closeness values offered by the Entropy-based TOPSIS algorithm that we developed.

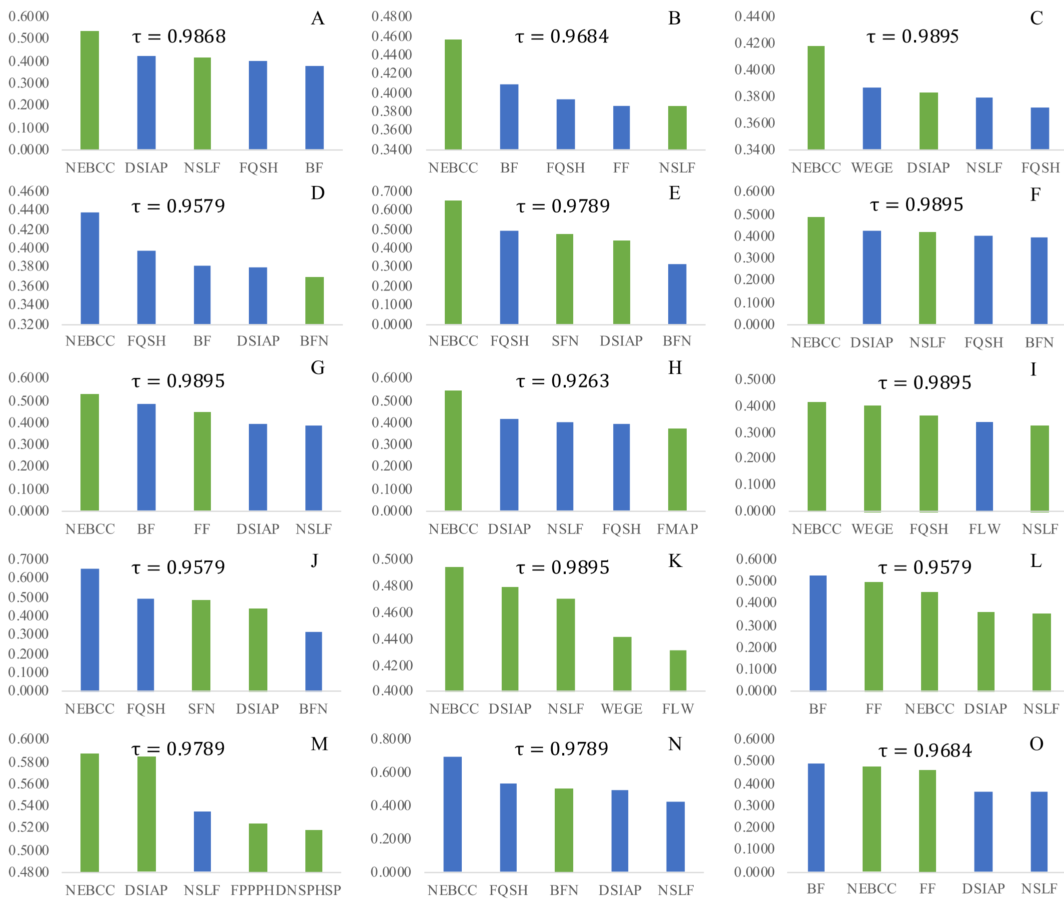

Figure 6.1 Top 5 of the NSA interventions and the Kendall's correlation coefficient (τ) for A) Ambikapathi et al., 2021; B) Berti andAraujo-Cossio, 2017; C) Blakstad et al., 2019; D) Daum et al., 2022; E) Di Prima et al., 2022; F) Kaminski et al., 2022; G) Port et al., 2017; H) Ma et al., 2021; I) Ojo et al., 2022; J) Saint-Ville et al., 2022; K) Sharma et al., 2021b; L) Sharma et al., 2021a M) Tizazu et al., 2022 N) Vinceti et al., 2022; and O) Warner et al., 2023. The green-shaded bars represent the types of NSA interventions that the studies chose to implement.

All five dimensions of the types of NSA interventions were present in the top results from the ranking: *Food production* (Figures 6.1A-6.1O) (diversification and sustainable intensification of agricultural production (DSIAP), nutrition sensitive livestock and fisheries (NSLF), biodiversity for food and nutrition (BFN) and biofortification (BF)), *Food processing* (Figures 6.1B, 6.1G, 6.1L, 6.1M, and 6.1O) (nutrition sensitive post-harvest handling, storage and processing (NSPHSP), and food fortification (FF)), *Food trade and marketing* (Figures 6.1H and 6.1M) (food marketing and advertising practices (FMAP), and food price policies for promoting healthy diets (FPPPHD)), *Consumer demand, food preparation and preferences* (Figures 6.1A-6.1O) (nutrition education and behavior change communication (NEBCC), and school food and nutrition (SFN)), and *Cross-cutting issues* (Figures 6.1A, 6.1B, 6.1C, 6.1D, 6.1E, 6.1F, 6.1H, 6.1I, 6.1J, 6.1K, and 6.1N) (women's empowerment and gender equality (WEGE), food loss and waste: prevention, reduction, and management (FLW), and food quality, safety and hygiene (FQSH)).

In almost all cases, the authors chose to implement the types of NSA interventions (green bars from Figure 6.1) that showed up in the top 5 of the ranked options from the entropy-based TOPSIS method. The NEBCC was on the top most of the time, making it clear that nutrition knowledge and norms is an almost indispensable outcome that should be considered when designing NSA interventions. Daum et al. (2022) (Figure 6.1D) studied the role of weeds for diets, while Vinceti et al. (2022) (Figure 6.1N) opted for building a portfolio with the wild trees of which fruit and other edible parts could improve dietary diversity throughout the seasons, both being examples of BFN; Saint-Ville et al. (2022) (Figure 6.1J), on the other hand, chose interventions of SFN and DSIAP. These are the three cases in which NEBCC was absent. Saint-Ville et al. (2022), however, included SFN, an intervention type that can also have an impact on care practices. Di Prima et al. (2022) (Figure 6.1E) chose both SFN and NEBCC, together with DSIAP.

The only cases in which the chosen types of NSA interventions were not in the top 5 of the suggested ones were Ma et al. (2021) (Figure 6.1H) and Sharma et al. (2021b) (Figure 6.1K). Ma et al. (2021) selected NEBCC, FMAP, and FPPPHD. The latter, however, was in the 7th place in the TOPSIS ranking, with a closeness value of 0.3406. Despite this, Kendall's τ was 0.9263 (Figure 1), which is still a good correlation coefficient. Sharma et al. (2021b) chose 6 types of NSA interventions, and 5 of them were in the top 5 from the entropy-based TOPSIS method. Income generation for nutrition, however, appeared in the 7th place of the ranking, with a closeness value of 0.4131, yet the Kendall's τ was 0.9895 (Figure 6.1K). These results prove that our algorithm has an overall outstanding performance at predicting the NSA interventions that are more suitable given the context of the project.

Once the types of NSA interventions are chosen, it is possible to select a pathway. For instance, the intervention by Ambikapathi et al. (2021) included the introduction of chickens of improved breeds to households, a NSLF intervention, and behavior change communication on women and children's nutrition, water, sanitation, hygiene, and women's empowerment, a NEBCC intervention. These interventions may have impacts on: on-farm availability, food access, diet quality, and natural resource management. Table 6.4 shows the recommended indicators corresponding to the outcomes and impacts that the authors considered in their theory of change. One of the benefits of having an algorithm like this one is that, in future interventions, the wrong selection of indicators (e.g., HDDS to measure diet quality when it actually measures food access) can be avoided. Another benefit is that the algorithm makes sure that at least one indicator is chosen from each impact or outcome appearing in the proposed pathway. For instance, Berti and Araujo-Cossio et al. (2017) did not choose NSA indicators to measure on-farm availability and care practices despite having those impacts contemplated in their theory of change (Table 6.3).

Table 6.4 NSA indicators that the algorithm suggests for each selected study.

Study	Suggested outcomes/impacts	Indicators for the suggested outcomes/impacts	Accumulated points
Ambikapathi et al. 2020	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.5196
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	1.6254
	Food access - Household level	Household Dietary Diversity Score (HDDS)	1.2289
	Food access - Household level	Household Food Insecurity Access Scale (HFIAS)	1.2256
	Natural resource management practices, health, and sanitation environment	Sustainability of water availability and water use efficiency measures	1.4127
	Diet quality - Individual level	Minimum Dietary Diversity–Young children (MDD-C)	0.6601
	Diet quality - Individual level	Minimum Dietary Diversity–women of reproductive age (MDD-W)	0.4608
	Care practices	Breastfeeding indicators	0.5886
Berti and Araujo-Cossio et al. 2017	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	2.8084
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	1.7172
	Diet quality - Individual level	Consumption of specific target foods	0.5898
	Diet quality - Individual level	Quantitative nutrient intakes	0.5830
	Care practices	Minimum Meal Frequency (MMF)	0.4858
Blakstad et al. 2019	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	2.8274
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.2467
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	2.2223
	Food access - Household level	Household Dietary Diversity Score (HDDS)	1.3591
	Income	Wealth indices/poverty levels	0.7379
	Diet quality - Individual level	Minimum Dietary Diversity–women of reproductive age (MDD-W)	0.7045
Daum et al. 2022	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.8054
	Natural resource management practices, health, and sanitation environment	Nutrition indicators for biodiversity	1.7089
	Natural resource management practices, health, and sanitation environment	Sustainability of water availability and water use efficiency measures	1.5374
Di Prima et al. 2022	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	8.7953
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.2713
	Food access - Household level	Household Dietary Diversity Score (HDDS)	0.9600
	Diet quality - Individual level	Minimum Dietary Diversity–Young children (MDD-C)	0.8640
	Diet quality - Individual level	Individual Dietary Diversity Score (IDDS)	0.7862

Kaminski et al. 2022	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.8205
	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	2.8117
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	1.9166
	Income	Wealth indices/poverty levels	0.8430
	Diet quality - Individual level	Consumption of specific target foods	0.7608
	Diet quality - Individual level	Quantitative nutrient intakes	0.7516
Port et al. 2017	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.9183
	Nutritional status	Anemia	1.8812
	Nutritional status	Iron status	1.6233
	Food access - Household level	Household Food Insecurity Access Scale (HFIAS)	1.2482
	Income	Household asset index	0.7173
	Diet quality - Individual level	Consumption of specific target foods	0.6021
	Food environment in markets	Availability of specific foods in markets	0.5308
	Care practices	Minimum Meal Frequency (MMF)	0.5023
Ma et al. 2021	Food access - Household level	Household Dietary Diversity Score (HDDS)	0.9959
	Income	Income or consumption	0.9083
	Food environment in markets	Prices of particular foods in markets	0.8266
	Food environment in markets	Food prices	0.8148
Ojo et al. 2022	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.8091
	Women's empowerment	Women's Empowerment in Agriculture Index (WEAI)	1.8145
	Natural resource management practices, health, and sanitation environment	Access to an improved drinking water source	1.7921
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	1.6506
	Nutritional status	Underweight	1.5225
	Nutritional status	Wasting	1.4590
	Nutritional status	Maternal weight/BMI	1.4185
	Income	Wealth indices/poverty levels	1.0655
	Income	Sales of agricultural products	1.0534
	Food access - Household level	Household Hunger Scale (HHS)	0.8949
	Diet quality - Individual level	Consumption of specific target foods	0.5831
	Diet quality - Individual level	Minimum Dietary Diversity–women of reproductive age (MDD-W)	0.5214
	Care practices	Minimum Acceptable Diet (MAD)	0.3244
Saint-Ville et al. 2022	Nutritional status	Underweight	2.9392
	Nutritional status	Stunting	2.8949
	Nutritional status	Wasting	2.8928
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.2713
	Care practices	Minimum Meal Frequency (MMF)	0.9590
	Diet quality - Individual level	Minimum Dietary Diversity–Young children (MDD-C)	0.8640
	Food environment in markets	Functional diversity index	0.8569
Sharma et al. 2021b	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	8.1276
	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	8.0246
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	2.2548

	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.2299
	Women's empowerment	Asset ownership by gender	1.9259
	Food access - Household level	Months of Adequate Household Food Provisioning (MAHFP)	1.5906
	Income	Sales of agricultural products	1.3233
	Food environment in markets	Indicators of food safety within the food environment	0.9475
	Care practices	Breastfeeding indicators	0.8618
	Care practices	Minimum Meal Frequency (MMF)	0.8618
	Diet quality - Individual level	Minimum Dietary Diversity–Young children (MDD-C)	0.8347
	Diet quality - Individual level	Minimum Dietary Diversity–women of reproductive age (MDD-W)	0.6850
Sharma et al. 2021a	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	3.4525
	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	3.3665
	Nutritional status	Underweight	2.9022
	Nutritional status	Stunting	2.7960
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.1859
	Food access - Household level	Household Dietary Diversity Score (HDDS)	1.2504
Tizazu et al. 2022	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	8.7183
	Nutrition and food safety knowledge and norms	Nutrition and food safety-related knowledge	8.6801
	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.2169
	Food access - Household level	Household Hunger Scale (HHS)	1.5204
	Care practices	Minimum Meal Frequency (MMF)	0.9549
	Care practices	Minimum Acceptable Diet (MAD)	0.9549
	Diet quality - Individual level	Minimum Dietary Diversity–Young children (MDD-C)	0.8551
	Diet quality - Individual level	Consumption of 400g fruits and vegetables per day	0.7400
Vinceti et al. 2022	On-farm availability, diversity and safety of foods	Diversity of foods produced on-farm	2.1743
	On-farm availability, diversity and safety of foods	Availability of specific foods on-farm	2.1218
	Natural resource management practices, health, and sanitation environment	Nutrition indicators for biodiversity	1.5125
	Food access - Household level	Months of Adequate Household Food Provisioning (MAHFP)	1.3740
	Food access - Household level	Food Consumption Score (FCS)	1.3278
	Diet quality - Individual level	Minimum Dietary Diversity–women of reproductive age (MDD-W)	0.6204
Warner et al. 2022	Nutrition and food safety knowledge and norms	Changes in specific behaviors promoted about food safety	3.2660
	Nutritional status	Stunting	2.6985
	Nutritional status	Vitamin A status	1.6399
	Nutritional status	Iron status	1.4953
	On-farm availability, diversity and safety of foods	Functional diversity index	1.4767

Food access - Household level	Household Dietary Diversity Score (HDDS)	1.0407
Food access - Household level	Food Insecurity Experience Scale (FIES)	0.9187
Food environment in markets	Functional diversity index	0.7326
Diet quality - Individual level	Vitamin A-rich food consumption	0.6039
Diet quality - Individual level	Iron-rich food consumption	0.3110

6.5 Conclusions

Although the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision analysis method, can be helpful when designing NSA interventions, it still has a subjective aspect, which is the assigning of the attributes' weights. To solve this issue, the entropy method was applied, determining the weights by using only objective data. The Entropy-based TOPSIS was tested by obtaining the necessary information from 15 published studies to respond the questionnaire and find out whether the algorithm was good at predicting the most suitable types of NSA interventions. The Kendall's correlation coefficients ranged from $\tau = 0.9263$ to $\tau = 0.9895$, proving an overall outstanding performance, and making this tool a promising one not only to select the types of NSA interventions, but also to make sure that the designer selects the proper NSA indicators to measure each outcome or impact that they consider in their theory of change. For future work, a smartphone app should be developed with the entropy-based TOPSIS algorithm.

CONNECTING TEXT

In the previous chapter, we integrated the entropy method to reduce subjectivity when assigning weights in the developed algorithm that identifies the types of NSA interventions and the most suitable indicators based on the selected pathways. Chapter VII addresses the fifth objective of this thesis, which is to create the blueprints of a smartphone application that would facilitate the task of designing an NSA project. The application is thought to adopt the algorithm from Chapter V, adding the entropy method from Chapter VI. The graphical user's interface along with the main features of the application are shown in Chapter VII. The smartphone application is expected to enhance the design of NSA interventions by avoiding designers to choose wrong indicators for what they intend to measure. The application is also anticipated to provide the tools to collect and analyze data. Chapter V has been presented at the American Society of Agricultural and Biological Engineers Conference, held virtually from 12th -16th July, 2021, co-authored by Dr. Michael Ngadi, Dr. Christopher Kucha, and Dr. Ebenezer Kwofie.

VII. BLUEPRINTS FOR THE SMARTPHONE APPLICATION AIMING TO IMPROVE THE DESIGN OF NUTRITION-SENSITIVE AGRICULTURE (NSA) INTERVENTIONS

7.1 Abstract

Designing a nutrition-sensitive agriculture (NSA) intervention can become an overwhelming task. Because of the abundance of metrics and indicators, it can become difficult to determine what each one reflects and what they do not reflect, which increases the risk of not selecting the most suitable tools to measure the impact of an NSA intervention. Based on an algorithm to select the types of NSA interventions and the types of NSA indicators, based on the context of a community and the priorities of the project designer, we developed the blueprints for a smartphone application. The overall framework of the App was shown, as well as its main features together with the graphical user's interface (GUI), which were created using the FIGMA software. Python is the programming language that is encouraged to be used to develop the App, because it can easily handle complex operations needed for the methodology involved in the multi-criteria decision analysis and the open-source resources, such as BeeWare that allows to write cross platform graphical user interface (GUI) Python applications.

7.2 Introduction

Designing a nutrition-sensitive agriculture (NSA) intervention can be challenging due to the fact that there are way too many factors to consider, not only the context (e.g., health status of children or women of reproductive age, type of agricultural activities performed, what is culturally appropriate to eat) of the community where the project is to take place, but also the numerous metrics and indicators with which the success or failure can be measured. Because of the abundance of metrics and indicators, it can become difficult to determine what each one reflects and what they do not reflect. For example, Verger et al. (2019) found that, at the household level, many studies are not consistent in terms of use and interpretation of simple food group dietary diversity indicators; the interpretation has been misleading in some cases (e.g., interpreted results of household dietary diversity score (HDDS) as a measure of diet quality, household nutrition or nutritional status when it really is a measure of food access).

In terms of instruments, there are different options, such as food records (FR), food frequency questionnaires (FFQ), and 24-h recall (24HR) to collect data concerning dietary or energy intake (Johnson, 2002) to determine the minimum dietary diversity for women of reproductive age (MDD-W) or other NSA indicators. Relevant information has been obtained from these self-reported methodologies, data that has been useful to develop public health policy, comprehend and identify consumption of different groups, understand relationship with diseases and determine eating patterns associated with weight loss. The problem with these methodologies is that they rely on human memory, which is not 100% accurate in recalling past behavior, making these methodologies unable to measure objectively (Archer et al., 2015; Dhurandhar et al., 2015). In addition to recall bias, these methods represent a significant researcher/individual burden and high cost of administration (Thompson et al., 2010).

There are innovative technologies, such as the automated wrist motion tracking (Dong et al., 2012), the bite-based model of kilocalorie intake (Salley et al., 2016), the automatic ingestion monitor (Fontana et al., 2014), the intelligent food-intake monitor (Liu et al., 2012), the digital photography plus recall (Ptomey et al., 2015), the remote food photography method (Martin et al., 2012), the real-time food recognition system (Kawano and Yanai, 2015), or the improved 24HR using a portable cameras (Bulungu et al., 2021; Matsushita et al., 2021). However, to our knowledge, no innovative methods have been developed to design NSA projects. Therefore, the objective of this chapter is to show the blueprints of a smartphone application that would show the most appropriate types of NSA interventions, based on the context and objectives of the user, would allow the user to select the most suitable metrics and indicators, and would also be used to collect and analyze data.

7.3 Materials and methods

7.3.1 Generating the graphical user's interface (GUI)

The blueprints for the overall design of the app were made. The main features that it would offer were outlined. The FIGMA software was used to draw the planned GUI. The programming language and the platform that would be used were discussed.

7.4 Results

7.4.1 Overall framework of the app design

In Figure 7.1, a simplification of the overall project framework is shown. A database will be built to store food information: bromatological composition, ingredients, and images. The database will be fed with different apps, such as diet assessment apps (e.g., app for assessing dietary diversity indicators). The pale blue section includes the part to which this chapter refers, the app that will be used to design NSA interventions, which will gather data from the database to build the metrics (e.g., 24-HR, FFQ, FR) to assess the desired NSA indicators.

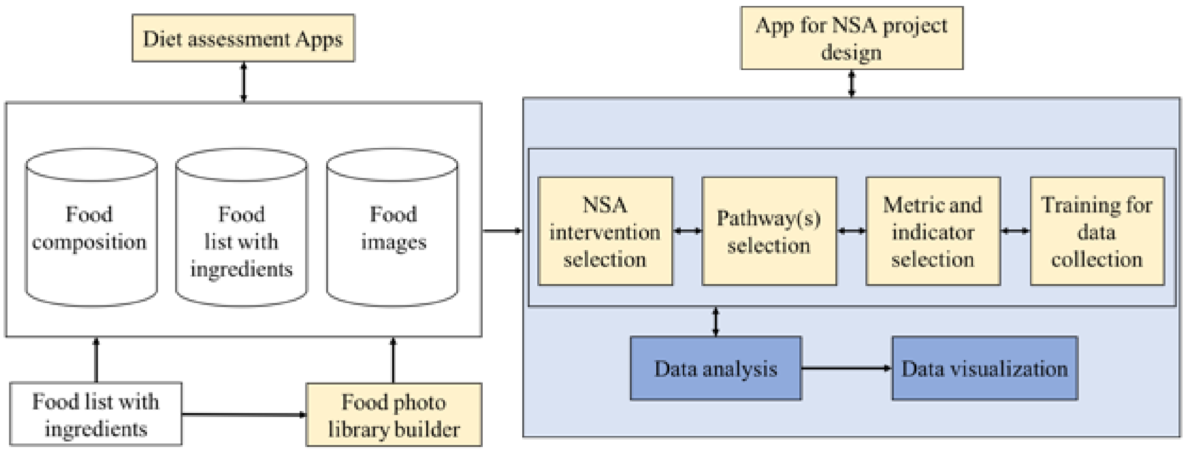

Figure 7.1 Overview of Nutrimetrics.

To access input from the users, a REST API will be required. This will interact with the database by inserting or fetching data giving the response in JSON or XML format that could be read by R, JSON Viewer, Excel or any other open-source program.

7.4.2 Main features of the App

7.4.2.1 Registration and main menu

1. Users can create an account (Figure 7.2 A)
2. Users can edit personal information (i.e., name, last name, email, email 2, job position, institution) (Figure 7.2 B)
3. Users can retrieve lost passwords
4. Users can change their passwords

5. Users can see the home page in which they can read a welcome message as well as our mission (Figure 7.2C) and the main menu (Figure 7.2D).

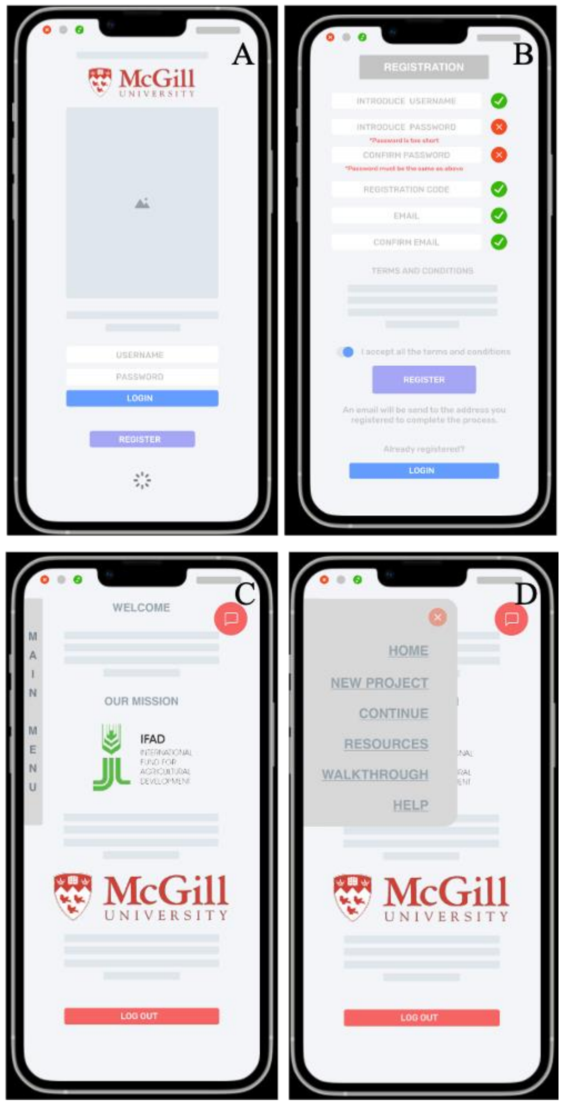

Figure 7.2 Blueprints of the graphical user interface of the app regarding the login (A), registration (B), welcome page (C), and main menu (D).

7.4.2.2 Walkthrough, resources and frequently asked questions (FAQ)

1. Users can access the walkthrough (i.e., instructions, step by step, on how to use the app)

(Figure 7.3A)

2. Users can access resources (e.g., external websites where they can find methodologies for indicators that are not supported by this app, such as biochemical measures) (Figure 7.3B)
3. Users can access help for frequently asked questions (FAQ) (Figure 7.3C)

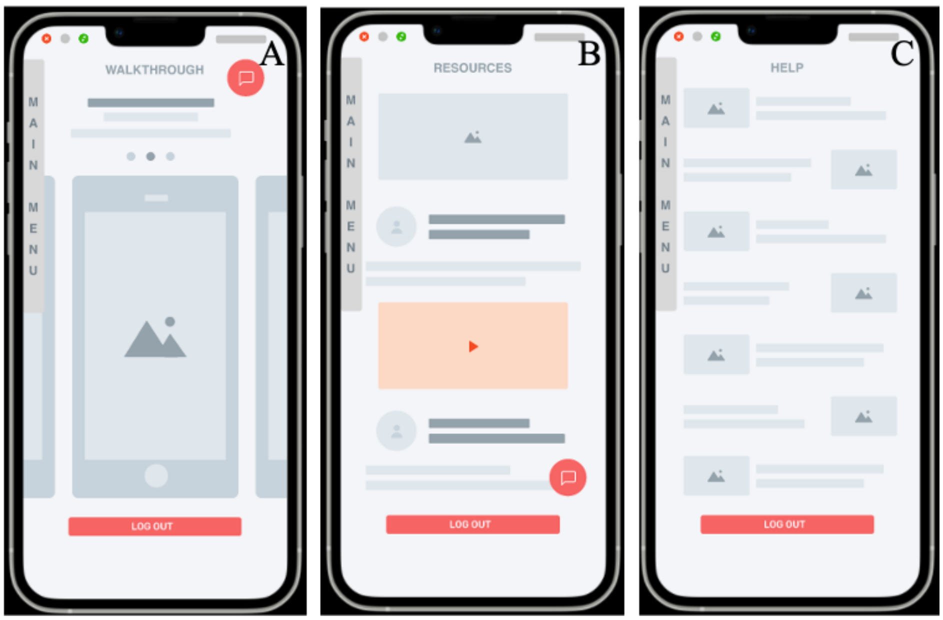

Figure 7.3 Blueprints of the graphical user interface of the app regarding the sections of walkthrough (A), resources (B), and help (C).

7.4.2.3 New projects

4. Users can name and rename the project
5. Users can add a brief description of the project (e.g., state the nutrition objectives)
6. Users can save/register unfinished projects (Figure 7.4A)
7. Users can create up to 3 projects (Figure 7.4B)

Figure 7.4 Blueprints of the graphical user interface of the app regarding the new project (A), and the continue section (B), where the different projects are displayed.

7.4.4.4 TOPSIS questionnaire and TOPSIS data entry

8. When clicking on a registered/saved project, users can answer the TOPSIS questionnaire (the one from *section 5.3.1*), and they may go back and forward in case they want to double check or modify their responses (Figure 7.5A)
9. Users can save unfinished questionnaires
10. Once the questionnaire is fully answered, users can edit the entry data of the TOPSIS (i.e., weights) if required (Figure 7.5B)
11. Users can undo any changes to the TOPSIS (set to default)

Figure 7.5 Blueprints of the graphical user interface of the app regarding the TOPSIS questionnaire (A), and the TOPSIS data entry (B).

7.4.4.5 TOPSIS outcome

12. Users can see the TOPSIS list of interventions (with their corresponding closeness value) after completing the questionnaire and adjusting the weights (Figure 7.6A)
13. Users can see a brief description of each type of intervention when clicking on them (Figure 7.6B)
14. Users can choose up to 4 types of interventions (must choose at least 1)
15. Users can change the chosen interventions

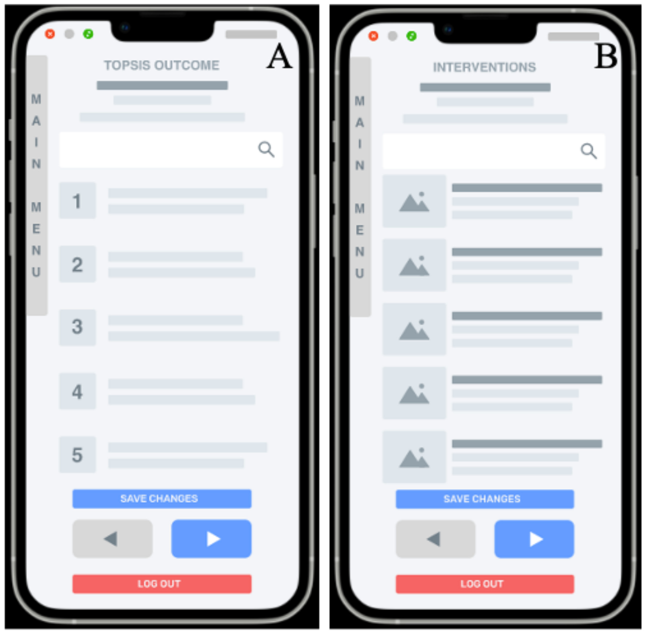

Figure 7.6 Blueprints of the graphical user interface of the app regarding the TOPSIS outcome (A), and the information (and examples) of each type of NSA intervention (B).

7.4.4.6 Pathways and indicators

16. Users can see the recommended pathways and a brief description of each one (Figure 7.7A)
17. Users can choose only 1 pathway for each project
18. Users can change the pathway
19. Users can see the list of indicators recommended for each step of the pathway (from the most relevant to the least relevant based on the accumulated points described in *section 5.3.3*) and a brief description of each one (Figure 7.7B).
20. Users must choose between 1 and 4 indicators for each step of the pathway

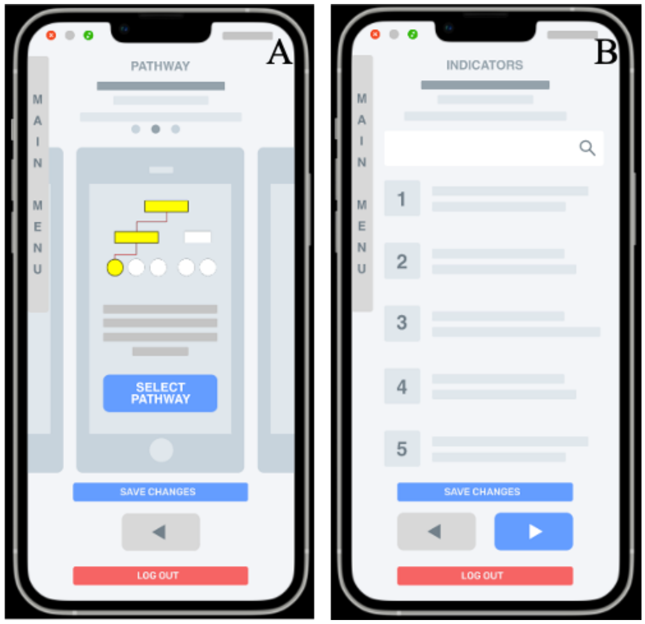

Figure 7.7 Blueprints of the graphical user interface of the app regarding the possible pathways (A), and the ranked suggested indicators (B).

7.4.4.7 Requirements for indicators and data upload

1. Users can see the features of the chosen indicators (e.g., what they measure, intended populations, such as women or children, instruments required to collect the data) (Figure 7.8A)
2. Users can see the materials on how to use the metrics and indicators
3. Users can choose the instruments (e.g., 24HR, FFQ) and collect data with them
4. Users can save unfinished data to each instrument (Figure 7.8B)
5. Users can change the data from each instrument

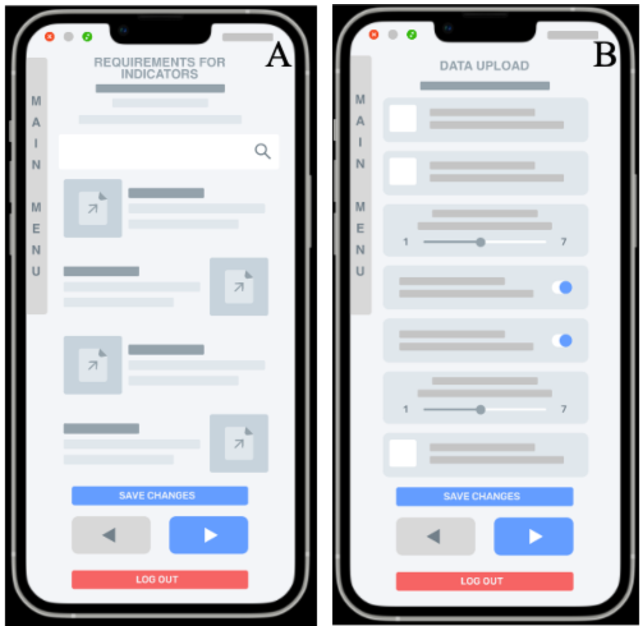

Figure 7.8 Blueprints of the graphical user interface of the app regarding the requirements for the selected indicators (A), the data for each selected instrument (B).

7.4.4.7 Indicators' results and data files from each instrument

6. Users can see the final results (e.g., tables, graphics) for each indicator (Figure 7.9A)
7. Users can retrieve the data of the final result in *CSV or *TXT (Figure 7.9B)
8. Users can retrieve *PDF documents of the TOPSIS list, the description of each intervention, the description of each indicator, the materials on how to use the metrics and indicators, the worksheet of each indicator and the final results.
9. Users can save the project at in any step

Figure 7.9 Blueprints of the graphical user interface of the app regarding the results from the data analysis (A), and the data files from each selected instrument (B).

7.5 Discussion

Though many back-end frameworks are currently used, the three main languages that currently dominate on the development of web applications are Python, Java and JavaScript (Richter, 2020). The advantage of using JavaScript is that only one language will suffice to develop both parts of the application as the Node.js framework can be used to work at the back-end development (Node.js, n.d.). Also, the asynchronous behavior of Node.js can be used to develop a much faster application since it can handle many connections concurrently due to non-blocking I/O (Node.js, n.d.). However, Node.js is known to rely heavily on NPM modules (Node.js, n.d.) that could not work properly in all mobile OS versions, and the complex operations needed to be performed in the TOPSIS methodology (*section 5.4.3*) would require a blocking I/O resulting in a computation delay.

Python's object-oriented syntax offers a cleaner, simpler and understandable code that allows multiple programmers to work simultaneously on the same app by using English terms rather than mathematical expressions to express complex ideas (MC, 2019). Besides, even though the low performance of Python in mobile apps is an issue, Python can easily handle complex operations needed for the methodology involved in the multi-criteria decision analysis (MCDA) and the open-source resources, such as BeeWare that allows to write cross platform graphical user interface (GUI) Python applications (Keith-Magee, 2013a). Therefore, Python is the programming language that will be used to develop the WebApp.

BeeWare works with a suite of tools and libraries that includes Toga, a native widget toolkit. This resolves the problem of Python not working very well with the native components of the mobile's OS. However, the GUI of Toga is not the most user-friendly, as its main components are the basic set of menu options that are found on every app (Keith-Magee, 2013b). However, other platforms and frameworks can be used to develop a smartphone application that could feed a database in which a Python back-end framework could operate in order to do the operations needed for the MCDA methodology.

7.6 Conclusion

There is a need to develop technological tools to improve the design of NSA projects. The MCDA methodology was used to help select the most appropriate types of NSA interventions and the most suitable indicators to measure their impact, based on the context of the population and the priorities of the user. The MCDA methodology should be integrated in a smartphone application able to provide the required tools for collecting and analyzing data. Such application, with Python as its programming language, is anticipated to help NSA project designers, managers, and stakeholders.

CONNECTING TEXT

After using the algorithm from Chapter V, it was identified that the interventions based on nutrition education were in the top interventions for the Bolivian context. Therefore, the design of a behaviour change communication program for Jesús de Machaca, a Bolivian community, took place, which is the sixth and final objective of this thesis. The typical dishes from Jesús de Machaca were investigated, as well as their nutritional facts so that behaviours based on what they already eat could be prioritized.

Chapter VIII presents a nutrition education program that can be easily implemented in Jesús de Machaca. This chapter was accepted to be presented at the 2023 CSBE/SCGAB conference, which took place in July, 2023, co-authored by Dr. Michael Ngadi, Dr. Christopher Kucha, and Dr. Ebenezer Kwofie.

VIII. A BEHAVIOR CHANGE COMMUNICATION PROGRAM FOR JESÚS DE MACHACA, A COMMUNITY IN BOLIVIA

8.1 Abstract

Since there are numerous types of nutrition-sensitive agriculture (NSA) interventions, many NSA indicators to measure their impact, as well as many other factors (e.g., context of the community) to consider when designing an NSA project, the task may become overwhelming. By using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision analysis (MCDA) method, it was determined that an intervention on nutrition knowledge was among the most suitable ones for Jesús de Machaca, a Bolivian population. Data on the local gastronomy was obtained: a total of 150 dishes were identified, and the composition (i.e., moisture, macronutrients, micronutrients, and caloric content) of each was assessed using the Bolivian table of food composition. Based on the context of the community, a behavior change communication (BCC) program was designed, aiming to improve the diet quality and, eventually, the health status of the population. Once the theory of change was formulated, pathways were prioritized using the following inputs: conceptual frameworks, published empirical evidence, a feasibility study, formative research, and local knowledge from the members of the Bolivian Association Pro-Rural. After prioritizing the key pathways, the specific behaviors to address were identified and prioritized. We based the prioritization on the formative research, local knowledge and impact pathways. The intervention is planned to be monitored using several types of NSA metrics and indicators. Impact and process evaluations will reveal whether these approaches are effective for improving the diet quality and health status, and what effects are on each hypothesized impact pathway.

Keywords: Diet quality; care practices; nutrition education; minimum dietary diversity for women (MDD-W)

8.2 Introduction

Certain health issues, such as heart disease, diabetes, several cancers, strokes, and adiposity, have been associated with dietary intake; and the changing food environment, with ultra-processed foods being an easily available cheap choice, as well as the high diffusion of information and communication technologies, automation, urbanization, aging, and other sociocultural transformations favor obesity-prone lifestyles (Ferretti and Mariani, 2019; Swinburn et al., 1999; Townshend and Lake, 2017). There are, however, public interventions promoting healthful behaviours through nutrition education, and their degree of impact varies (Briscoe and Aboud, 2012; Hardeman et al., 2002). Different approaches for this kind of intervention can be carried out: interpersonal counselling (Girard and Olude, 2012), motivational interviewing (Spahn et al., 2010), or Participatory Learning and Action (PLA) with groups (Biran et al., 2014; Nair et al., 2017; Saville et al., 2018). The degree of interaction can be sacrificed to reach a wider audience via mass media or text messaging.

Since there are numerous behaviors that an intervention can target, a key part of the process is to prioritize and decide how to change those behaviors, especially when health outcomes depend on several of them (Harris-Fry et al., 2020). For instance, reducing undernutrition can be attained by modifying diets, physical activity, hygiene, or food purchasing and production decisions (Black et al., 2013). Each of these behaviors can be dissected into specific actions, such as "eat one additional meal during pregnancy" or "introduce complementary foods at six months of age". This dissection increases the complexity of multisectoral interventions, and the task of a project implementor is to select both agriculture and nutrition-specific impact pathways and behaviors.

Once the behaviors have been chosen, subsequent analysis is needed to identify the best way to encourage their acceptance within the community. The relative importance of the enabling factors, classified as people's "capabilities", "opportunities", and "motivations", depend on contexts, seasons, and life stages (Michie et al., 2011). For instance, people may be at different stages of adopting a behavior —from thinking about it to trying it and continuing with it. At the moment of implementing an intervention, one should avoid aiming to change all the relevant behaviors or addressing all possible barriers, otherwise there could be information overload and choice fatigue among the participants, which would inhibit behavior change (Bawden and Robinson, 2009; Botti and Iyengar, 2006). The challenge, therefore, is to identify the intentions that should be chosen as well as the optimum number of them to promote.

'Behavior change wheel' is a tool useful to unpack the capabilities, opportunities and motivations that underlie a behavior (Michie et al., 2011). The use of more techniques to change behaviors is suggested to increase the effectiveness of an intervention, and there is information on the relative effectiveness of varying doses and coverage (Harris-Fry et al., 2020): increasing the number of women's groups per population increases impacts on neonatal mortality, and larger effects are also observed with increasing proportion of pregnant women attending groups; a recent evaluation of a radio program promoting vitamin-A-rich sweet potato showed that 44 episodes helped improve knowledge.

It is clear that dosage, coverage and number of techniques are factors that have an impact on the effectiveness of an intervention, but there is a lack of guidance on whether an intervention should aim to change many behaviors, or focus on just a few, or on how barriers to behavior change should be prioritized and addressed.

8.3 A case study from a nutrition-sensitive agriculture intervention in Bolivia

We provide a case study of a complex nutrition-sensitive agriculture (NSA) intervention that aimed to reduce maternal and child malnutrition (obesity) in a Bolivian rural community. Following the methodology by Harris-Fry et al. (2020), we describe how (1) we identified the most important pathways through which the interventions were hypothesised to improve nutrition outcomes, (2) prioritised behaviours and barriers to behaviour change to address within these pathways, (3) reviewed the intervention's content against these priorities, and (4) continually integrated community participants' reported priorities.

8.3.1 Study context, rationale and overview

Data from the Global Nutrition Report (2021) show the targets for maternal, infant and young child nutrition (MIYCN) that Bolivia is trying to achieve: anemia prevalence in pregnant and non-pregnant women has been reduced from 33.1% to 24.4% in the last two decades; whereas no progress has been made regarding birth weight, 7.2% of infants show a low weight at birth; 16.1% of children under 5 years of age are stunted (a prevalence higher than the average for the Latin America and Caribbean region (11.3%); 2% of children under 5 years of age are still affected by wasting, also higher than the average for the Latin America and Caribbean region (1.2%); with respect to childhood overweight, the prevalence is 10.1%.

Bolivia has made limited headway towards attaining the diet-related non-communicable diseases targets. About 28.4% of adult women and 16.8% of adult men (aged 18 and over) deal with obesity. These numbers, although lower than the regional values (30.7% for women and 22.8% for men) are alarming, since 10.1% of adult women and 7.8% of adult men suffer from diabetes. Throughout the Andes, including Bolivia, farming households have high activity levels and therefore high food energy intake from mostly tubers and grains, fewer high-nutrient density foods and fatty foods, which leads to inadequate diets (i.e., low in iron, zinc, vitamin A, riboflavin, vitamin B12 and folate, and dietary fat) (Berti and Araujo-Cossio, 2017).

Jesús de Machaca is a location in the La Paz Department, Bolivia, 114 km away from La Paz, the departmental capital (Figure 8.1). The Jesús de Machaca Municipality is the sixth municipal section of the Ingavi Province, and of the Jesús de Machaca Canton, and is at 3,870 m above sea level. Based on the national census, the population of Jesús de Machaca has been declining from 13,270 individuals in 2012 to 11,926 in 2022 (INE, 2022). Agriculture can be a key tool to improve nutrition outcomes. The families in Jesús de Machaca are involved in agricultural activities, such as the production of crops (e.g., potatoes, oca, quinoa, cañahua) and livestock rearing (e.g., cattle, sheep, small animals). Part of their production is destined to local consumption. There are also communities engaged in the dairy production (e.g., cheese, yogurt).

Figure 8.1 Location of Jesús de Machaca in La Paz, Bolivia (Image from Google Maps).

Programs promoting food production of nutrient-rich foods (e.g., biofortification, homestead gardens, livestock rearing) have shown a positive impact on dietary diversity, and the non-dietary pathways of behaviour change and women’s empowerment have been proven to enhance the results of nutrition outcomes in NSA interventions (Berti et al., 2016; Ruel et al., 2018; Webb and Kennedy, 2014).

Data on the local gastronomy was obtained from interviewing local people. A total of 150 dishes (divided into breakfasts, meals, snacks, suppers and beverages) were identified, and the composition (energy, humidity, total carbohydrates, fats, crude fiber, ashes, Ca, P, Fe, vitamin A, thiamine, riboflavin, cyanine, and vitamin C) of each was determined using the Bolivian table of food composition (Ministerio de Salud y Deportes, 2005). With that information, the total nutritional value was calculated (1 portion per person).

The NSA intervention variants have been selected as follows:

1. Biweekly women's groups viewing and discussing presentations on NSA and nutrition-specific behaviors (without agriculture content), plus home visits.
2. Biweekly women's groups viewing and discussing presentations on NSA and nutrition-specific behaviors, combined with a cycle of group meetings, plus home visits. With the help of the presentations, these PLA meetings are thought to encourage members to collectively understand the problems of malnutrition (e.g., obesity), and then to identify, prioritize and act on locally feasible solutions to address this problem.

Local staff are planned to facilitate the presentation disseminations, PLA meetings and home visits, and the interventions will be open to all women in the community, although men will not be discouraged from observing the disseminations and meetings. The interventions will begin with community mobilization activities, and training of program staff on maternal and child nutrition, hygiene and NSA. The two interventions will be compared with a control arm receiving standard government services and a 2-day nutrition training to government female community health workers, provided in all arms. The interventions are planned to last about one year.

8.3.2 Unpacking possible behaviours to prioritize

Figure 7.2 shows an example of the multiple pathways, behaviors and associated capabilities, opportunities and motivations that might change a single health outcome. There are several ways to improve nutrition through NSA interventions (left-hand box; Figure 8.2). Within a pathway there are many crops or agricultural behaviors that could be promoted (middle box; Figure 8.2), and people may have several capabilities, opportunities or motivations that can be developed to enhance the behavior change (right-hand box; Figure 8.2).

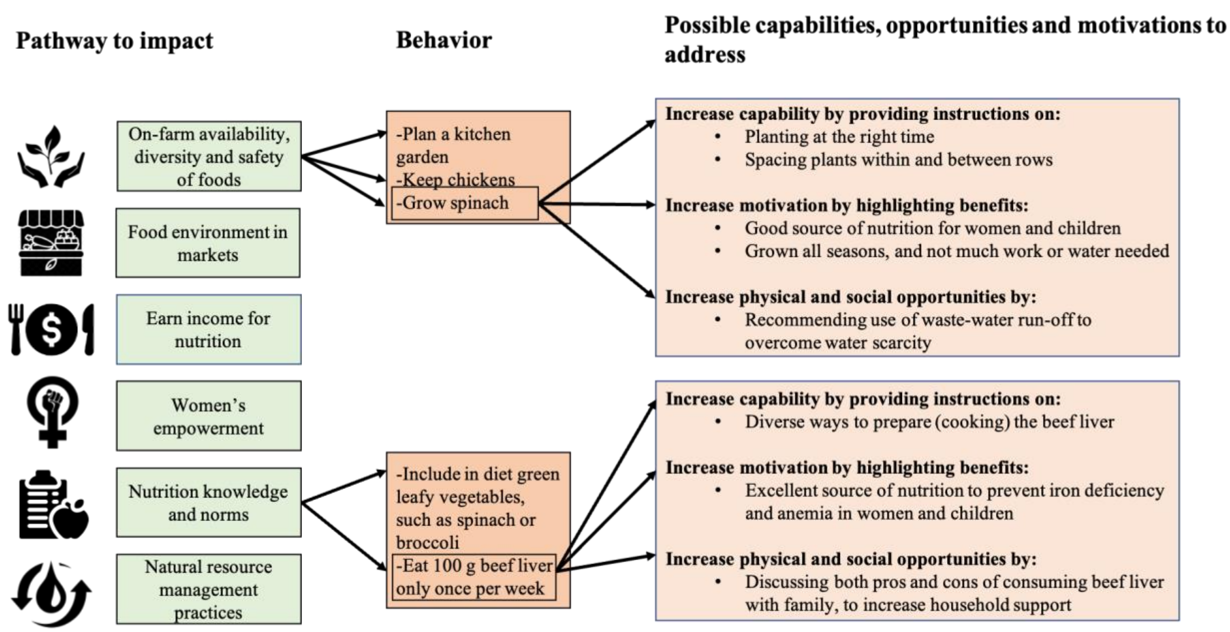

Figure 8.2 Unpacking the possible pathways, behaviors and capabilities, opportunities and motivations that could be prioritized in the project.

8.3.3 Stages of intervention development

Figure 7.3 shows the key stages by which we prioritized which topics to address in the presentations, PLA meetings, and home visits. First, it was hypothesized which NSA and nutrition-specific pathways were most likely to have a positive impact on the outcomes by collectively developing a definition of ‘nutrition-sensitive agriculture’ and a Theory of Change that outlined possible impact pathways. The second step was to prioritize specific behaviors within the pathways. Finally, from the prioritized pathways (in the Theory of Change) and associated prioritized NSA and nutrition-specific behaviors (from the formative research), we identified capabilities, opportunities and motivations to be addressed in each presentation or PLA meeting and associated home visit.

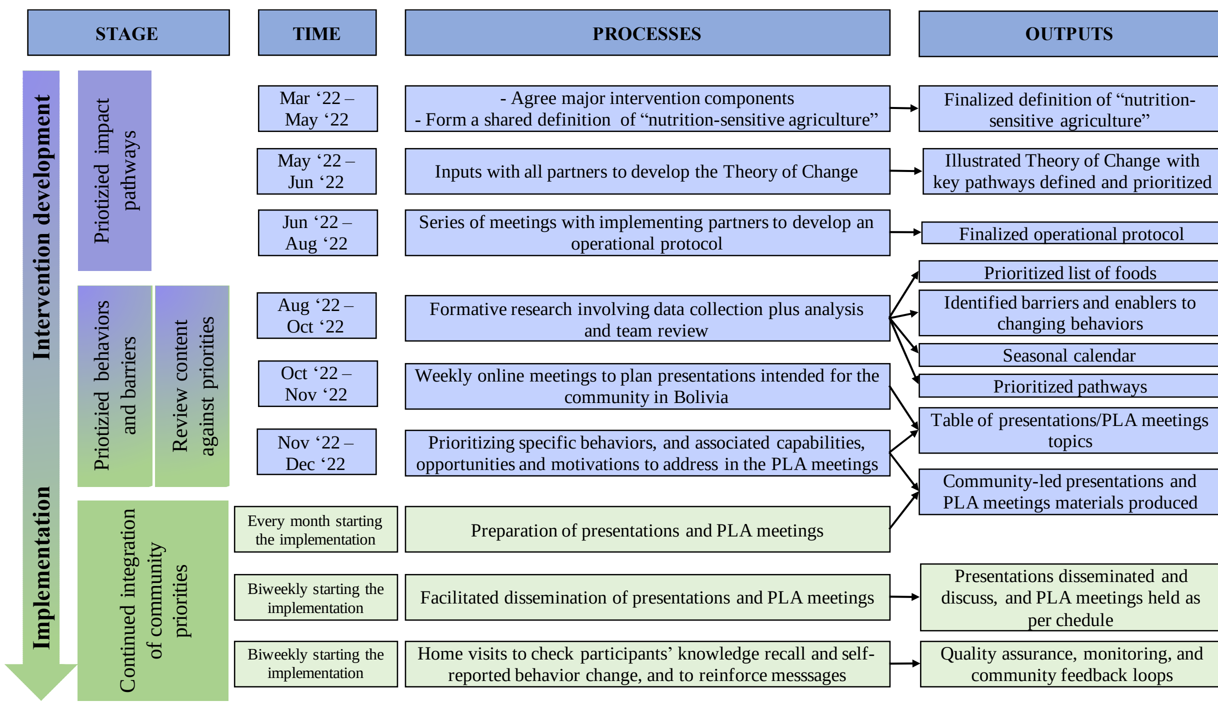

Figure 8.3 Key stages in the development and prioritization of the nutrition-sensitive agriculture (NSA) intervention. PLA, Participatory Learning and Action.

8.4 Prioritizing impact pathways

To decide on the priority pathways the following inputs were used: conceptual frameworks, published empirical evidence, a feasibility study, formative research, and local knowledge from the members of the Bolivian Association Pro-Rural.

8.4.1 Existing conceptual frameworks

Different conceptual frameworks have been suggested to prove the links between agriculture and nutrition (Haddad, 2000; Herforth and Ballard, 2016; Kadiyala et al., 2014; Kanter et al., 2015). We grounded our working definition of "nutrition-sensitive agriculture" and our Theory of change in these frameworks, and only included pathways and practices relevant for our study, which were determined using the TOPSIS methodology, as shown in Chapter 5. Therefore, macro-level factors, such as domestic food trade and health infrastructure and employment, were ignored as they would not have been realistically influenced by our intervention. Instead, we focused on household and intra-household-level factors, such as agricultural production, women's empowerment and nutrition knowledge.

8.4.2 Existing empirical evidence

Although infection might seem like a factor that should be considered when talking about improving the nutritional status of women and children (Drakesmith and Prentice, 2012; Guerrant et al., 1992), a PLA group intervention in India had a positive impact on hand washing practices but showed no effect on child illness (Nair et al., 2017), and another trial found no effect of a water, sanitation and hygiene intervention on child length (Humphrey et al., 2019), which can be attributed to exposures to other multiple infection risks. Therefore, although the importance of hand washing was emphasized as a preventive measure, infection reduction was not the focus; instead, we promoted other practices, such as hygiene when handling foods when cooking (e.g., practices to avoid cross-contamination). The pathway of seeking care from a nurse or a doctor was deprioritized because of the limited quality of care with this respect within the community.

8.4.3 Feasibility study and formative research

Before starting intervention activities, feasibility research and formative research will be performed. The formative research will be led by technical experts from Pro-Rural, in collaboration with members from the Bioresource Engineering Department of McGill University.

The aim of the research is (1) to understand what is considered culturally appropriate within the community, (2) develop a list of foods, crops and livestock used in the local gastronomy as well as their nutritional value, (3) identify barriers and enablers to changing agriculture and nutrition behaviors, and (4) to create a seasonal calendar of agricultural processes, cash flows, labor and gender roles. Focus group discussions, a participatory food ranking using pile sorts, an exercise to fill out daily activity charts for participants and their family members, and direct observation via transect walks through selected spots.

Contextual information will be obtained to confirm the relevant pathways to follow towards a change. It has been published that focus group discussions determined that it could be possible to reduce women's workload, and heavy or time-consuming tasks could be shifted to other adult members in the household (Harris-Fry et al., 2020).

8.4.4 Local knowledge from the implementation team

We will draw from the local team knowledge about agricultural and nutrition practices and barriers to change. For starters, improving value-chain pathways will not be considered (e.g., improving cold storage facilities for agricultural produce), because the time frame does not realistically allow to change them. But food production is one of the top type of interventions, and income for agriculture can be generated from this increase in food production. Together, as discussed in Chapter 5, these two can have an impact on food access and eventually diet quality (Figure 5.6).

8.5 Prioritizing behaviors and barriers

After prioritizing the key pathways, the specific behaviors to address were identified and prioritized. We based the prioritization on the formative research, local knowledge and impact pathways.

8.5.1 Formative research and local knowledge

To prioritize the NSA behaviors, we looked at crops and livestock as well as the typical dishes consumed within the community, and prioritized foods based on:

- Time of year
- Nutritive value
- Economic value
- Labor requirements (for cooking)
- Cost and accessibility of ingredients required
- Feasibility of adoption

To identify which nutrition-sensitive agricultural behaviors to promote within a prioritized food or crop, we identified what feasible change was most important. Similar to Berti et al. (2016), the local team determined whether the food crop or dish was new to the area but could be promoted, or whether it was already produced but practices could be improved. The next step was to fill gaps in the presentations and PLA meeting calendar with behaviors that were less time-sensitive yet relevant, such as presentations explaining the concept of NSA, or household budgeting.

For each behavior, the reasons why the practice was not being performed already will be written down (e.g., beliefs that certain foods are harmful for children or pregnant women). The presentations therefore will be focused on dismantling myths about food and nutrition. The team will also look for ways to address multiple pathways concurrently. For instance, a presentation focused on cooking dishes that require minimal labor and are of high nutritional value. Cooking those dishes could improve the nutritional status and reduce women's expenditure simultaneously.

Recognizing that the prevalence, appropriateness, and feasibility of nutrition and agricultural practices would vary due to different factors (e.g., wealth, season), a breadth of perspectives was taken into account in the formative research. When facilitating the group discussions, meeting content will be personalized according to the participants. Group members will discuss barriers and solutions to adoption that may be more relevant for them (e.g., water scarcity, restrictive gender roles), and they will share their experience with each other. The PLA meetings will be specifically designed to be culturally appropriate because groups themselves identify and prioritize salient problems, solutions and strategies to implement.

8.5.2 Reviewing intervention content in relation to our priorities

The content of both the presentations and group meetings will be reviewed every 6 months in order to assess whether each pathway is being given equal weight. Some pathways are easier to address than others. For instance, it is hypothesized that the promotion of nutrient-rich foods for household consumption is conceptually simple, as opposed to increasing women's empowerment in terms of decision-making in the household.

As shown in Table 8.1, each specific promoted behavior will be mapped against the transtheoretical model of behavior change (Prochaska and DiClemente, 1982), based on whether the behavior is generally: (1) new to the community (‘pre-contemplation’); (2) being considered (‘contemplation’); (3) of interest to the community (‘preparation’); (4) being first adopted (‘action’); (5) being continued (‘maintenance’) or (6) being modelled to others in the community (‘termination’). This mapping exercise makes it possible to be systematic in guaranteeing balance across pathways and track behavior change stages, and makes it easier to stay focused on a confined, core set of behaviors.

8.5.3 Continued integration of community priorities

Once the intervention is being implemented, community feedback will be considered, as illustrated in Figure 8.4. To balance expert opinion, evidence and community priorities, decisions will be made through consultation with the group meeting facilitators. To create the presentations, a script, based on the agreed behaviors and barriers, was written in Spanish, the local language. Feedback from facilitators and protagonists will be obtained. After showing the presentations, facilitators will discuss with the participants the appropriateness of the presentations, reasons why they may not adopt promoted behaviors, and ideas of new topics, all of which informed future presentations. A list of nutrition-specific behaviors was identified from the formative research and the local knowledge to create cards for the participants to discuss together in order to prioritize and find strategies to implement. Therefore, PLA groups will discuss a common set of topics related to maternal and child undernutrition, but each group will prioritize differently the issues they wanted to address as well as the strategies to implement.

Table 8.1 An example of mapping presentations with specific behaviors, capabilities, opportunities and motivations addressed, to the main pathway and transtheoretical behavior change stage.

Title of the presentation	**Main prioritized pathway(s)**	**Specific behaviors promoted**	**Capabilities, opportunities, and motivations addressed**	**Transtheoretical behavior change stage**
Benefits of growing spinach	Nutrition knowledge and norms, diet quality, and care practices	-Grow spinach -Children and pregnant women eat the spinach produced	-**Motivate** participants to grow spinach by emphasizing benefits (source of income and nutritious food)	Contemplation
How to practice home gardening to grow vegetables	Food access, and women's empowerment	-Keep a program of irrigation for the different vegetables -Families decide who should care for the gardens and what to do with the produce and income from surplus	-Increase **capabilities** to improve home gardening by providing instructions - Increase women's social **opportunities** to be involved in decisions about workload and use of vegetable produce and income by promoting joint decision-making	Preparation
How to practice home gardening to grow vegetables	On-farm availability, diversity and safety of foods, and nutritional status	-Grow vegetables -Children and pregnant women eat the vegetables produced	-**Motivate** participants to grow vegetables by emphasizing benefits (source of income and nutritious food)	Action

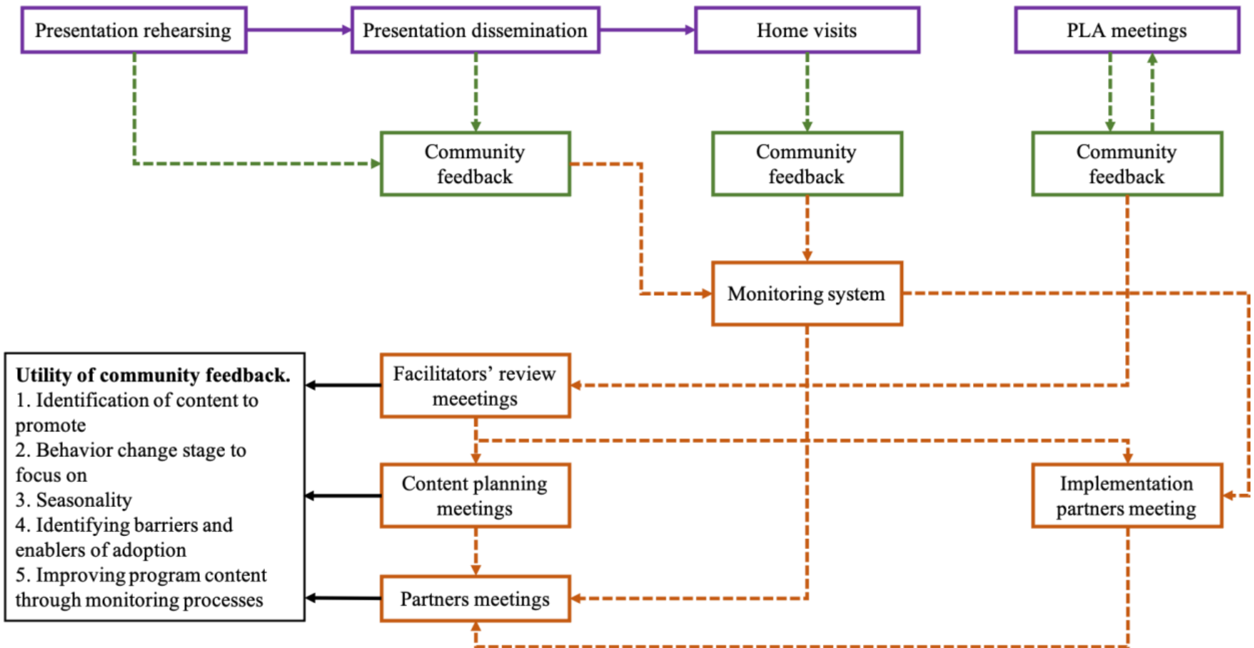

Figure 8.4 Flow of community feedback in the nutrition-sensitive agriculture (NSA) intervention. PLA, Participatory Learning Action.

Some women might feel shy when it comes to speak up in the group meetings. Home visits are expected to be an opportunity for them to discuss quietly the relevance of, and enablers and barriers to, promoted behaviors. During the home visits, facilitators will also gather data on participants' recall of the messages shown in the presentations or discussed in the group meetings, and their adoption of promoted behaviors.

This feedback will be collected by the Pro-Rural team during monthly review meetings with the group facilitators, and will be used to make adjustments in the planned content and review progress. The quantitative data collected during the home visits will be analyzed to quantify coverage gaps, knowledge recall and behavior adoption. Based on feedback from participants and group facilitators, new topics will be introduced and popular topics will be repeated.

8.6 Impact evaluation

The impact of the NSA intervention will be measured through cross-sectional household surveys at baseline (before the implementation) and endline (after the implementation), in the same intervention and control clusters.

8.6.1 Trial outcomes

Maternal BMI was selected as outcome measures for nutritional status for adults. BMI can determine the percentage of the population who suffers from obesity, which has been associated with other non-communicable diseases, such as diabetes, hypertension and some types of cancer (Garton et al., 2020). Dietary diversity scores for adults and children are selected as validated indicators of dietary adequacy of multiple micronutrients (Arimond et al., 2010; Working Group on Infant and Young Child Feeding Indicators, 2006). These scores capture short-term dietary improvements; thus, they may also be amenable to change within the timeframe of this trial. Indicators for on-farm availability, diversity and safety of foods, food access, diet quality, care practices, nutrition knowledge and norms, women's empowerment are also included. All the outcomes and indicators are shown in Table 8.2.

8.6.2 Sample size

The sample size would be selected so that it has 80% power with a 5% level of significance to detect a 9% absolute difference in child dietary diversity between the intervention and control arms. This sample would allow us to detect a difference in mean maternal BMI of 0.3 kg/m^2 between the intervention and the control clusters (Kadiyala et al., 2018).

Table 8.2. Trial outcomes.

Outcome	Indicator
On-farm availability, diversity and safety of foods	• Diversity of foods produced on-farm (count of number of crops or livestock produced) (Sibhatu et al., 2015)
Food access	• Household dietary diversity score (HDDS) (FAO, 2016)
Diet quality	• Minimum dietary diversity—young children (MDD-C), portion of children 6-23 months of age who receive foods from 4 or more food groups (of 7) • Minimum dietary diversity—women of reproductive age (MDD-W), percentage of mothers or female primary caregivers consuming ≥ 5 out of 10 groups per day (24-h recall)
Nutrition knowledge and norms	• Nutrition and food safety related knowledge and attitudes (KAP) at the community level • Changes in specific behaviors promoted (e.g., children and pregnant women eat spinach)
Care practices	• Minimum Acceptable Diet (MAD), portion of children (aged 6-23 months) receiving the WHO-recommended MAD
Women's empowerment	• Women's decision making (percentage of women empowered in women's decision making in productive and health-related domains, aggregated, measured using the Women's Empowerment in Agriculture Index (WEAI)
Nutritional status	• Maternal overweight (Mean body mass (BMI) (kg/m^2)) of non-pregnant, non-postpartum (gave birth > 42 days ago), mothers or female primary caregivers of children aged 0-23 months

8.6.3 Data collection and management

Before data collection, a census should be performed to identify the households with a child aged 0-23 months in the clusters. A random sample from each cluster will be invited to participate in a baseline survey, and they will be asked to provide a written informed consent. The documents for the survey and the consent will be adapted and translated from the baseline questionnaires shown by Kadiyala et al. (2018), which includes questions for female caregivers about nutrition, health, and empowerment in agriculture, and questions for male participants about agriculture and socio-economic status.

One of the advantages of this study is that part of the data collection will be through 'Diet DQ Tracker', a smartphone app developed by our team. This smartphone application was designed for real-time meal recording from a list of pre-defined food items, including food name, constituent ingredients, portion size or number of servings, as well as where the meal was prepared or consumed. 'Diet DQ Tracker' displays three of the indicators that are of interest for our study: MDD-W, MDD-C, and HDDS, which are usually obtained by an interviewer, who asks questions from a questionnaire regarding food intake; the information recorded on paper is later used to calculate manually the diet diversity intake, using food composition tables or a specific software. It is fair to say that 'Diet DQ Tracker', as the first smartphone application designed for data collection on dietary intake in resource-poor settings, reduces the interviewing's workload, and allows respondents to track their meals in their own time.

Data collectors and supervisors will organize into teams to collect data over one month prior to implementation start; this will be repeated for one month for the endline survey. Supervisors will collect anthropometric measures to calculate the maternal BMI, while data collectors will conduct the rest of the interview to determine the diversity of foods produced on farms, the nutrition and food safety related knowledge and attitudes at the community level, the changes in specific behaviours promoted by the intervention, and WEAI.

8.6.4 Analysis plan

The analysis and presentation of the intervention's results will follow the Consolidated Standards of Reporting Trials (CONSORT) Statement for cluster randomized controlled trials (Campbell et al., 2012). To verify imbalances between arms, descriptive statistics of demographic and outcome measures at baseline will be tabulated.

8.7 Discussion

8.7.1 Study limitations

Despite the plan of getting a project that will be powered enough to test the differences between the interventions, there is the possibility that this will not be the case due to the large size required to do so and the limited resources at hand. Since the components of the project are not cumulative, the study will not unravel the effects of the individual components within the interventions. This is attributed to the fact that, in order to minimize the burden on participants across the intervention arms, the number of meetings (video disseminations or PLA) were standardized to two per month. If the interventions were cumulative, so would have been the number of meetings, which would hinder identifying whether the effect was due to the number of meetings or the meeting content.

8.7.2 Study implications

The main goal of this project is to improve both the maternal and child nutrition through education on nutrition and agricultural activities. The project will inform how to strengthen diet quality and care practices to enhance, eventually, the nutrition status among the members of a rural community. This study will be a robust source of evidence on how agricultural diversity can be improved through participatory, low-cost, and video-based approaches. This project will prove whether maternal and child nutrition can be enhanced by integrating nutrition-specific messages, and it will always be useful to determine the optimal participatory action to improve nutrition outcomes. These interventions will contribute on showing how women groups have the potential to represent an effective platform for holistic NSA interventions.

8.7.3 Future work

Process and economic evaluations should also be performed to obtain critical data to determine translational feasibility and scale up. By doing so, this methodology could be adopted at scale by managers and designers of NSA interventions around the world. Regarding the 'Diet DQ Tracker', different databases of food and beverages were taken as a starting point: USDA's Food and Nutrient Database for Dietary Studies (FNDDS;2017-2018), Laos' ASAEN food composition database (electronic version; 2014-01-01), and Ethiopia's food composition table for use in Ethiopia Part III (1968-1997): 8777 food products both raw and cooked (e.g., steamed, boiled, roasted, fried) from a variety of categories are contained in the food application's database. The idea is to feed the database with information from other countries to get local accurate assessments of the different indicators.

IX. GENERAL SUMMARY AND CONCLUSIONS

9.1 General summary and conclusions

Since most of the rural poor communities perform agricultural activities, agriculture has been regarded as a key strategy to fight against malnutrition. Agriculture has been evolving, from an approach heavily focused on the production of maize, corn, rice, and other caloric staple crops, to one that takes into consideration fruit, vegetables, nuts, and other crops that had been neglected. Despite the increase in the production of nutritious crops, micronutrient deficiencies persist in vulnerable communities. Therefore, changes in agriculture have been made, which has resulted in a more holistic approach: the nutrition-sensitive agriculture (NSA). The NSA approach aims to produce, in a sustainable manner, a wide variety of nutritious, affordable, culturally appropriate, high-quality, and safe foods to satisfy the dietary requirements of vulnerable communities.

There are different types of NSA interventions, and they include non-dietary pathways, so the first step was to classify them into different categories within the food system: food production (e.g., nutrition-sensitive livestock and fisheries); food handling, storage and processing (e.g., food fortification); food trade and marketing (e.g., food price policies); consumer demand, food preparation and preferences (e.g., nutrition education and behavior change communication); and cross-cutting issues (women's empowerment). NSA projects have better chances of improving the nutrition status when interventions are designed as multi-pathway approaches. For instance, increasing the production of a biofortified crop as well as the income generation via agricultural sales while, simultaneously, a behavior change communication program is implemented to improve the care practices.

There are several tools to collect data when evaluating the impact of an NSA intervention, such as food records (FR) food frequency questionnaires (FFQ), 24-hour recalls (24HR), and other modern methods and technologies (e.g., smartphone applications that feature real-time food recognition systems). From the collected data, some indicators can be assessed to determine the diet quality (e.g., minimum dietary diversity for women in their reproductive age (MDD-W)), food access (e.g., household hunger scale (HHS)), on-farm availability, women's empowerment, etc. It is ideal to use as many indicators as needed to measure each step of the pathway that an NSA intervention follows. Due to the high number of types of interventions, instruments to collect data, and indicators, the task of designing a set of interventions can become overwhelming. Therefore, we suggested the use of the multi-criteria decision analysis (MCDA) techniques to optimize the design of NSA interventions.

A systemic review was performed to determine the most commonly types of interventions chosen for current NSA projects. It was observed that the most frequent categories were food production, and consumer preferences. Regarding cross-cutting issues, women's empowerment has gained popularity as an indirect nutrition approach. Diet quality, food access, and nutritional status indicators were the most common selections. Some projects are designed in such a way that indicators are wrongly used (e.g., household dietary diversity score (HDDS) taken as a diet quality parameter when it actually measures food access). It was found that many interventions had low statistical power or failed to be lasting enough to perceive significant changes in nutritional status (anthropometric measures). These findings demonstrate that there is a need to optimize the design of NSA interventions, and MCDA might be helpful.

MCDA involves many methods that support the decision maker in their own unique and personal decision process to find a solution. Several studies that deal with agricultural problems have used different MCDA techniques, such as the analytic hierarchy process (AHP) to determine the soil erosion and degradation as well as to identify areas suitable for agricultural land reform, or the multi-attribute value theory (MAVT) to measure the sustainability level of agricultural systems, or the preference ranking organization method for enrichment evaluation (PROMETHEE) to evaluate and rank the climate change adaptation practices regarding tillage for maize cultivation. To our knowledge, however, MCDA techniques have not been tested to design NSA interventions. Each method has its limitations and particularities, making it impossible to determine whether one makes more sense than another in a specific problem situation. There are, however, some ways of choosing appropriate MCDA methods: one way is to look at the data and parameters of the method and the modeling effort, as well as looking at the outcomes and their granularity. The technique for order preference by similarity to ideal solution (TOPSIS) was chosen because it requires a relatively minimal number of inputs from the user, and because its output easy to understand.

By using a questionnaire that pondered the objectives and the priorities of project managers, a ranked list of the types of NSA interventions was obtained using the closeness values (CV) from TOPSIS. To reduce subjectivity when weighting the normalized decision matrix, both Laotian and Bolivian contexts were considered, performing Mann-Kendall trend tests on indicators from different aspects: food availability, food access, food utilization, and food stability. The top three types of interventions were: nutrition education and behavior change communication (CV = 0.6157), nutrition-sensitive livestock and fisheries (CV = 0.5921), and diversification and sustainable intensification of agricultural production (CV = 0.5456). Once the types of intervention are chosen, this methodology allows the user to select the pathway(s) towards improving the nutrition status. Based on the selected pathway(s), the user may choose from another ranked list of indicators which to use to measure the impact. This ranking was made using the accumulated points from the answers given by the user in the questionnaire.

To avoid the need of assigning manually the attributes' weights, the Entropy method (EM) was included in the developed TOPSIS algorithm. The entropy-based TOPSIS was then tested with data (e.g., theory of change, reported food security context, indicators that they use to measure outcomes and impacts) from published studies to validate it. The Kendall's correlation coefficient (τ) was used to check whether our algorithm's suggestions aligned or not with the types of NSA interventions that the authors from the studies chose to implement. The correlation coefficients went from $\tau = 0.9263$ to $\tau = 0.9895$, making this tool a promising one for NSA project designers.

Using the developed entropy-based TOPSIS algorithm to select types of NSA interventions and indicators, we designed the blueprints for a smartphone application. The overall framework of the application was shown as well as its main features together with the graphical user's interface (GUI), which were created using the FIGMA software. Python is the programming language that is encouraged to be used to develop the application, because it can easily handle complex operations required for the TOPSIS method and the open-source resources, such as BeeWare, that allows to write cross platform GUI Python applications. Since this smartphone app would represent a platform not only to select the most suitable types of NSA interventions (based on the nutrition objectives and the context of the community where the project is to take place), but also to obtain information on the metrics to collect and analyze data, it would be so useful for project managers, implementors, and stakeholders to improve the design of the interventions.

Finally, since one of the top types, based on the CV from the TOPSIS algorithm, was nutrition education and behavior change communication, a program of this kind was designed for Jesús de Machaca, a Bolivian community. Data on the local gastronomy was obtained: a total of 150 dishes were identified, and the composition of each was assessed using the Bolivian table of food composition. The purpose of this was to identify those foods rich in micronutrients (e.g., iron) from which women and children suffer deficiencies. The pathways were prioritized using conceptual frameworks, published empirical evidence, a feasibility study, formative research, and local knowledge from the members of the Bolivian Association Pro-Rural. The next step was to identify and to prioritize the specific behaviors to address (e.g., eating spinach). Then, the metrics and indicators were selected, MDD-W, MDD-C, and HDDS will be measured using ‘Diet DQ Tracker’, a smartphone app designed and developed by our team for real time food recording, which will be less time-consuming than conventional methodologies.

X. CONTRIBUTION TO KNOWLEDGE AND RECOMMENDATIONS FOR FUTURE WORK

10.1 Contributions to knowledge

This study of nutrition-sensitive agriculture (NSA) interventions has resulted in the following original contributions to knowledge:

1. To the author's knowledge, this is the first study that classified current NSA projects into different categories of the food system, to understand their core characteristics and to validate their methodologies in terms of counterfactual analysis, power, program theory of change, and heterogeneity.
2. This study represents the first attempt to apply the technique for order preference by similarity to ideal solution (TOPSIS), a multi-criteria decision analysis (MCDA) method, to help improve the design of NSA projects.
3. For the first time, an algorithm was developed to determine, quantitatively, which instruments and indicators are the most suitable ones, depending on what pathways a project is designed to follow towards improving the nutrition status.
4. The blueprints of the smartphone application, first of its kind, represents a platform that contains relevant information not only on the types of NSA interventions, but also on how to use the instruments and tools to collect and analyze data.
5. A protocol for the implementation of a behavior change communication (BCC) program was presented in detail, suggesting the use of 'Diet DQ Tracker', the first self-administered smartphone application designed for collecting and evaluating dietary data for diet quality indicators (i.e., MDD-W and MDD-C), and a food access indicator

(i.e., HDDS), which will make more efficient the assessment of the impact of the program.

10.2 Recommendations for future work

There are some things that are required from this project. Validation of the TOPSIS method would be the first one. Although it was validated using data from published studies, it still needs to be tested for new projects. A sample of volunteers, experts in the design of NSA interventions, would be invited to participate in this process. They would be asked to respond the questionnaire, and to evaluate the ensuing ranked list of types of NSA interventions to make a statistical analysis (using rank correlation methods) on how well the decisions from the algorithm and the experts align.

Once the TOPSIS method is fully validated, with the corresponding corrections, the smartphone application should be developed, so that it can work together with the 'Diet DQ Tracker' to collect and analyze data. These apps could be expanded so that other NSA indicators can be included, such as the Women Empowerment in Agriculture Index (WEAI).

The implementation of the behavior change communication (BCC) program for Jesús de Machaca should be implemented. If this NSA intervention succeeds in improving diet quality and care practices, the next step should be to measure the nutrition status not only with the maternal BMI, but using other anthropometric and biochemical measures.

APPENDIX

A1. Questionnaire developed for the TOPSIS methodology

	Questions	Possible answers*
1	How long does the intervention intend to last?	Weeks/ Months/ Years
2	Is it an agriculture-based community?	Yes/No
3	Is the intervention focused on technology for behavior change communication (e.g., development of apps, webpages, video commercials, etc., to propagate key messages on nutrition education)?	Yes/No
4	Is the project intended to change the agricultural landscape (i.e., the result of interactions between farming activities and the natural setting in an area)?	Yes/No
5	Are you planning to measure the height of children under 5 years of age?	Yes/No
6	Are you planning to measure the weight of children under 5 years of age?	Yes/No
7	Are you planning to measure weight and height of mothers?	Yes/No
8	Are you planning to determine whether children under 5 years of age are deficient or replete in iron?	Yes/No
9	Are you planning to determine whether women of reproductive age are deficient or replete in iron?	Yes/No
10	Are you planning to measure the hemoglobin level in children under 5 years of age?	Yes/No
11	Are you planning to measure the hemoglobin level in women of reproductive age?	Yes/No
12	Are you planning to determine whether children under 5 years of age are deficient or replete in vitamin A?	Yes/No
13	Are you planning to determine whether women of reproductive age are deficient or replete in Vitamin A?	Yes/No
14	How important is it to know the economic food access of a household?	
15	How important is it to know the nutritional status of a household?	
16	How important is it to know the nutritional status of an infant (0 – 23 months old)?	
17	How important is it to know the nutritional status of a toddler (2 - 5 years old)?	
18	How important is it to know the health status of an infant (0 – 23 months old)?	

19 How important is it to know the health status of a toddler (2 - 5 years old)?

20 How important is it to know the health status of a lactating woman?

21 How important is it to know the health status of a pregnant woman?

22 How important is it to know the health status of a woman of reproductive age (15 – 49 years old)?

23 How important is it to know the micronutrient intake of a household?

24 How important is it to know the micronutrient intake of an infant (0 – 23 months old)?

25 How important is it to affect the nutrient-rich foods in markets?

26 How important is it to improve the diversity of commonly consumed foods?

27 How important is it to improve the community-level production diversity?

28 How important is it to assess the cash and non-cash remuneration for work or investments and gifts received by a household or individual?

29 How important is it to determine women's income and control of assets (e.g., participation in decisions on how money should be used)?

30 How important is it to determine women's participation when it comes to make decisions regarding agricultural issues?

31 How important is it to decrease the vulnerability of the female population within the community?

32 How important is the role of women within the community? (i.e., domestic labour, child care, cooking, etc.)

33 How important is it to know the details about how women spend their time (i.e., percentage of time spent daily in household on paid and nonpaid activities, disaggregated; division of labor and responsibility within the household)?

34 How important is it to know about the knowledge regarding social norms that affect caregiving (e.g., breastfeeding) and feeding/eating practices?

35 How important is it to measure the nutrient adequacy and dietary diversity of women of reproductive age (15-49 years)?

36 How important is it to determine the nutrient adequacy and dietary diversity of children between 2 and 14 years old?

37 How important is it to determine a proxy for dietary quality (i.e., Diversity, adequacy, moderation, overall balance)?

38 How important is it to quantify specific information on precise nutrient intakes?

39 How important is it to know if individuals are meeting the WHO recommendations for fruit and vegetable consumption?

40 How important is it to take into account chronic disease and obesity among the target population?

41 How important is it to improve the consumption of Vitamin A-rich foods?

42	How important is it to improve the consumption of Iron-rich foods?
43	How important is it to track the consumption of foods that will be promoted?
44	How important is it to consider the seasonal variation of physical access to safe and nutritious foods?
45	How important is it to consider the fluctuation of prices of foods in markets?
46	How important is it to measure the seasonality of the products consumed?
47	How important is it to address the food insecurity of a household?
48	How important is it to measure the severity of the food insecurity experience?
49	How important is it to measure the household access to and consumption of a variety of foods?
50	How important is to measure the household frequency of consumption of targeted foods? (i.e., specific foods that contains high levels of a vitamin or mineral)
51	How important is it to measure household access to and consumption of diverse food, weighted by nutrient density?
52	How important is it to measure the food insecurity experience in Latin America and the Caribbean?
53	How important is it to obtain a cross-culturally valid measure of the severity of food insecurity experience?
54	How important is it to identify vulnerable households and estimate long-term changes in food security?
55	How important is it to measure the perceived household food adequacy throughout the past year to reflect the seasonality aspect of food security?
56	How important is it to improve the food production in the community?
57	How important is it to measure the availability of diverse nutritious foods?
58	How important is it to improve the availability of diverse nutritious foods?
59	How important is it to determine a proxy for micronutrient density of staple crops produced on farm?
60	How important is it to improve the safety of agricultural production?
61	How important is it to measure the post-harvest loss?
62	How important is it to take into account the current marketing strategies for healthy foods?
63	How important is it to determine the farmer's and food producers' compliance with the safety regulations (e.g., implementation of good hygiene practices in food production)?
64	How important is it to know the prices of certain foods in markets?
65	How important is it to know the price of a basic food basket?

66	How important is it to measure the minimum cost of a diet meeting minimum requirements of macro- and micronutrients of food-based dietary guidelines?
67	How important is it to assess the diverse nutritious foods?
68	How important is it to determine the reduction of chemical or microbiological contaminants in products offered to consumers at retail?
69	How important is it to determine the compliance of product with national regulations for specific products?
70	How important is it to measure the amount of decrease in safe and nutritious food mass available for human condition in the different segments of a specific supply chain?
71	How important is it to affect household income?
72	How important is it to correlate income and food or health care purchases?
73	How important is it to track the wealth and/or socioeconomic status of the community?
74	How important is it to measure the value of incremental sales (collected at farm-level) attributed to project implementations?
75	How important is it to measure the Household Consumption and Expenditure (e.g., living standards, household budget, etc.)?
76	How important is it to measure the sets of key assets within the household?
77	How important is it to measure women's control over critical parts of their lives in the household, community and economy (i.e., decisions about agricultural productions; access to and decision-making power over productive resources; control over use of income; leadership in the community; and time use?
78	How important is it to measure women's empowerment relative to men within their households?
79	How important is it to measure the access to productive resources (e.g., land and water; farm inputs; farm implements, assets and technologies; credit; extension services and training programs) based on gender?
80	How important is it to promote certain nutrition behavior or messages?
81	How important is it to understand the likelihood of consumption of specific foods?
82	How important is it to understand the overall dietary patterns for various population sub-groups (e.g., pregnant or lactating women, children)?
83	How important is it to assess the nutrition and food safety-related knowledge and attributes (KAP) at the community level?
84	How important is it to measure the awareness about safety at household (consumers') level?

85	How important is it to determine the frequency, duration, or completeness of breastfeeding?
86	How important is it to track progress at improving key quality and quantity dimensions of children's diet based on standards of nutrient and energy density and feeding frequency?
87	How important is it to assess a proxy for energy intake from non-breastmilk foods among young children?
88	How important is it to affect soil or water management?
89	How important is it to affect the livestock-human interactions?
90	How important is it to measure the percentage of population using an improved drinking water source?
91	How important is it to determine the risk of environmental enteropathy?
92	How important is it to measure the percentage of delivered versus required water or number of farmers with secure access to water?
93	How important is it to count the number of foods consumed with a sufficiently detailed description to identify genus, species, subspecies and variety/cultivar/breed, with at least one value for a nutrient or other bioactive component?
94	How important is it to determine the water quality to be used in food production (from primary production to consumers)?
95	How important is it to assess the contamination of soils (natural, industrial)?
96	How important is it to adopt mitigating practices by farmers/producers (modification in agricultural practices; change of use of soils)?
97	How important is it to determine the percentage of wastewater being treated/produced?

*When not indicated, the possible answers may be: Does not apply / Not very important / Somewhat important / Important / Very Important.

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