Nutritional and hemoglobin status in relation to dietary micronutrient intake: studies in female and male small-scale farmers from Lindi region, Tanzania, and Gurué district, Mozambique

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Summary

Background: Inadequate consumption of micronutrient-dense and protein-rich foods, such as vegetables, legumes and meat, are important contributing causes for malnutrition, anemia and micronutrient deficiencies in rural communities of Tanzania and Mozambique. The increasing public health concern of the malnutrition form of overweight has repeatedly been reported in urban as well as rural areas of Sub-Sahara Africa and may have already reached farmers in Tanzania and Mozambique. Nutritional status is assessed by anthropometry, dietary intake and hemoglobin. Compared to the often-used body mass index (BMI) and traditional 24-hour recall, the mid-upper-arm-circumference (MUAC), as well as a food group-based algorithm (CIMI) can be suitable additional assessment tools, especially in resource poor environments.

Methods: Cross-sectional studies within the framework of the Vegi-Leg project were conducted to assess the nutritional status (anthropometrics and hemoglobin measurements), and the dietary behaviours (Household Dietary Diversity Scores (HDDS), Food Frequency Questionnaires (FFQ) and 24-hour recalls) of female and male farmers from rural areas of Tanzania and Mozambique. Data were analysed by region, sex, age, partly season (Tanzania) and correlates. Additional data from similar projects, namely Scale-N and Trans-SEC in rural villages of Tanzania were included in MUAC and CIMI analysis. MUAC as an additional and easy-to-handle anthropometric marker for underweight, as well as overweight was evaluated using data from Vegi-Leg and Scale-N surveys. MUAC cut-offs, calculated via BMI cut-offs (<18.5, ≥25, and ≥30 kg/m^2) and multiple linear regression (MLR), compared to those selected by highest Youden's index (YI) value, were assessed. The CIMI algorithm included 23 food groups and was tested in comparison to NutriSurvey (detailed quantitative 24 hour recalls) with data from Scale-N and Trans-SEC.

Results: A total of 1526 farmers from the Vegi-Leg project (669 from Tanzania, 857 from Mozambique) were studied, of whom 19% were overweight and 35% were anemic. The study showed an overall higher prevalence of overweight (19%) than underweight (10%), mainly due to the high prevalence of overweight female farmers (up to 35%) in southern Tanzania. The highest prevalence of overweight and anemia, at 35% and 48%, was observed in Tanzanian and Mozambican women, respectively. Regarding HDDS and FFQ data, pigeon pea farmers in Lindi and Gurué reported high consumption frequencies of cereals, legumes, vegetables and oil, while meat, fish and eggs were only consumed rarely. Overall, only a small proportion of enrolled women and men reached the recommended daily dietary intake of vitamin A (10%), iron (51%) and zinc (44%) according to the 24-hour recalls. Multiple regression models revealed that dark green leafy vegetables (DGLVs) highly predicted vitamin A intake, whereas legumes in Tanzania and starchy plants in Mozambique were the dominant sources of vitamin

A. Cereals contributed to over half of the iron and the zinc intake in both countries. Seasonal analysis revealed high fluctuations for the consumption frequency of food items from the food groups ‘legumes and pulses’, ‘green leafy vegetables’, ‘other vegetables’ and ‘fruits’, including tomatoes, pigeon peas, mangoes and oranges. The results from Lindi Tanzania revealed, that in seasons, when the availability of food groups like fruits, legumes or vegetables was low, the consumption frequency decreased significantly.

BMI, which correlated positively and strongly with MUAC, was higher in Tanzania than in Mozambique and higher among female than male farmers, and decreased significantly from the age of 65 years. MUAC cut-offs of <24 cm and ≥30.5 cm, calculated by multiple linear regression, detected 55% of farmers being underweight and 74% being overweight, with a specificity of 96%; the higher cut-off <25 cm and lower cut-off ≥29 cm, each selected according to Youden’s Index, consequently detected more underweight (80%) and overweight farmers (91%), but on the basis of a lower specificity (87–88%).

The results of the algorithm CIMI and NutriSurvey were similar with regard to the average intake and range of data distribution. The correlation coefficients of NutriSurvey and CIMI with regards to energy (0.931), protein (0.898), iron (0.775) and zinc (0.838) intake, supported the matching of both calculations.

Conclusion: An increased consumption of micronutrient-rich DGLVs and legumes, while reducing the high amounts of refined sugar, maize and polished rice, is suggested to counteract the high prevalence of anemia and overweight among smallholder farmers in rural Tanzania and Mozambique. MUAC cut-offs to detect malnutrition whether defined via linear regression or Youden’s Index, proved to be easy-to-use tools for large-scale rural screenings of both underweight and overweight. The food group based CIMI algorithm is a valid instrument that calculates energy and nutrient intake in agreement with the preferred nutrition software NutriSurvey.

Zusammenfassung

Hintergrund: Der unzureichende Verzehr von mikronährstoff- und eiweißreichen Lebensmitteln wie Gemüse, Hülsenfrüchten und Fleisch ist eine wichtige Ursache für Mangelernährung, Anämie und Mikronährstoffmangel im ländlichen Tansania und Mosambik. Die zunehmenden Zahlen von Übergewicht und Fettleibigkeit wurden bereits mehrfach in sowohl städtischen als auch ländlichen Gebieten Subsahara-Afrikas ermittelt und haben möglicherweise bereits die Bauern in Tansania und Mosambik erreicht. Der Ernährungszustand wurde durch Anthropometrie, Nahrungsaufnahme und Biomarker wie Hämoglobin ermittelt. Im Vergleich zum häufig verwendeten Body-Mass-Index (BMI) und der traditionellen '24-hour recalls' könnten der mittlere Oberarmumfang (MUAC) sowie ein auf Lebensmittelgruppen basierender Algorithmus (CIMI) zu schnelleren und effizienteren Bewertungen führen, insbesondere in ressourcenarmen Umgebungen.

Methoden: Im Rahmen des Vegi-Leg-Projekts wurden Querschnittsstudien durchgeführt, um den Ernährungszustand (Anthropometrie und Hämoglobinmessungen) und das Ernährungsverhalten (Household Dietary Diversity Scores (HDDS), Food Frequency Questionnaires (FFQ) und 24-hour-recalls) von Bäuerinnen und Bauern aus ländlichen Gebieten in Tansania und Mosambik zu bewerten. Die Daten wurden nach Region, Geschlecht, Alter, teilweise Saison (Tansania) und Korrelaten analysiert. Zusätzliche Daten aus ähnlichen Projekten, nämlich Scale-N und Trans-SEC in ländlichen Dörfern Tansanias, wurden in die MUAC- und CIMI-Analyse einbezogen. Der MUAC als zusätzlicher und einfach zu handhabender anthropometrischer Marker für Unter- und Übergewicht wurde anhand von Daten aus Vegi-Leg- und Scale-N-Erhebungen bewertet. Es wurden MUAC-Cut-offs, die über BMI-Cut-offs (<18,5, ≥25 und ≥30 kg/m^2), und multiple lineare Regression (MLR) im Vergleich zu den nach dem höchsten Youden-Index (YI) ausgewählten Werten berechnet wurden, bewertet. Der CIMI-Algorithmus umfasste 23 Lebensmittelgruppen und wurde im Vergleich zu NutriSurvey (detaillierte quantitative 24-hour-recalls) mit Daten von Scale-N und Trans-SEC getestet.

Ergebnisse: Es wurden insgesamt 1526 Bäuerinnen und Bauern aus dem Vegi-Leg-Projekt (669 aus Tansania, 857 aus Mosambik) untersucht, von denen 19 % übergewichtig und 35 % anämisch waren. Die Studie ergab eine insgesamt höhere Prävalenz von Übergewicht (19 %) als von Untergewicht (10 %), was hauptsächlich auf die sehr hohe Prävalenz von übergewichtigen Bäuerinnen im Süden Tansanias zurückzuführen ist. Die höchste Prävalenz von Übergewicht und Anämie wurde mit 35 % bzw. 48 % bei tansanischen und mosambikanischen Frauen festgestellt. Was die HDDS- und FFQ-Daten betrifft, so gaben die Bäuerinnen und Bauern in Lindi und Gurué an, häufig Getreide, Hülsenfrüchte, Gemüse und

Öl zu konsumieren, während Fleisch, Fisch und Eier nur selten verzehrt wurden. Gemäß den 24-hour-recalls, erreichte insgesamt nur ein kleiner Teil der teilnehmenden Frauen und Männer die empfohlene tägliche Zufuhr von Vitamin A (10 %), Eisen (51 %) und Zink (44 %). Multiple Regressionsmodelle ergaben, dass der Konsum (in Gramm) von dunkelgrünem Blattgemüse (DGLV) die Vitamin-A-Aufnahme in hohem Maße positiv beeinflusste, während Hülsenfrüchte in Tansania und stärkehaltige Pflanzen in Mosambik die tatsächlichen Hauptquellen für Vitamin A waren. Die saisonale Analyse ergab starke Schwankungen bei der Verzehrshäufigkeit von Lebensmitteln aus den Lebensmittelgruppen "Hülsenfrüchte", "grünes Blattgemüse", "sonstiges Gemüse" und "Obst", einschließlich Tomaten, Straucherbsen, Mangos und Orangen. Die Ergebnisse aus Lindi in Tansania zeigten, dass in den Jahreszeiten mit geringerer Verfügbarkeit an Nahrungsmitteln wie Obst, Hülsenfrüchten oder Gemüse auch deren Verzehrhäufigkeit deutlich zurückging.

Der BMI, der positiv und stark mit dem MUAC korrelierte, war in Tansania höher als in Mosambik und bei weiblichen höher als bei männlichen Bauern und nahm ab einem Alter von 65 Jahren deutlich ab. Die mittels multipler linearer Regression berechneten MUAC-Grenzwerte von <24 cm und ≥30,5 cm wiesen bei einer Spezifität von 96 %, 55 % der Landwirte als untergewichtig und 74 % als übergewichtig aus: der höhere Grenzwert <25 cm und der niedrigere Grenzwert ≥29 cm, die jeweils nach dem Youden-Index ausgewählt wurden, wiesen folglich mehr untergewichtige (80 %) als auch mehr übergewichtige Landwirte (91 %) aus, allerdings auf der Grundlage einer niedrigeren Spezifität von 87-88 %.

Die Ergebnisse des Algorithmus CIMI und NutriSurvey waren hinsichtlich der durchschnittlichen Aufnahme und der Datenverteilung ähnlich. Die Korrelationskoeffizienten von NutriSurvey und CIMI in Bezug auf die Energie- (0,931), Protein- (0,898), Eisen- (0,775) und Zinkaufnahme (0,838) unterstützen die Übereinstimmung der beiden Berechnungen.

Schlussfolgerungen: Ein erhöhter Verzehr von mikronährstoffreichen Lebensmitteln und Hülsenfrüchten bei gleichzeitiger Reduzierung des hohen Anteils an raffiniertem Zucker, Mais und poliertem Reis wird vorgeschlagen, um der hohen Prävalenz von Anämie und Übergewicht unter Kleinbauern im ländlichen Tansania und Mosambik entgegenzuwirken. MUAC-Grenzwerte zur Erkennung von Mangelernährung, die entweder über eine lineare Regression oder den Youden-Index definiert werden, haben sich als einfach zu handhabende Instrumente für groß angelegte ländliche Screenings von Unter- und Übergewicht erwiesen. Der auf Lebensmittelgruppen basierende CIMI-Algorithmus ist ein valides Instrument, das die Energie- und Nährstoffaufnahme in Übereinstimmung mit der bevorzugten Ernährungssoftware NutriSurvey berechnet.

List of Publications/ Manuscripts included in this dissertation

Accepted and published

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Submitted to: International Journal of Food Sciences and Nutrition (10.08.2023)

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Abbreviations

BMI	Body Mass Index
CIMI	Calculator of Inadequate Micronutrient Intake
DBM	Double Burden of Malnutrition
DGLV	Dark Green Leafy Vegetables
FANTA	Food and Nutrition Technical Assistance
FAO	Food and Agriculture Organization
FFQ	Food Frequency Questionnaire
Hb	Hemoglobin
HDDS	Household Dietary Diversity Score
HRQL	Health-Related Quality of Life
MN	Micronutrient
MZ	Mozambique
MUAC	Mid-Upper Arm Circumference
NCDs	Non-communicable diseases
RE	Retinol Equivalents
RDI	Recommended Daily Intake
SSA	Sub-Sahara Africa
SENS	Sensitivity (true positive rate)
SPEC	Specificity (true negative rate)
TBM	Triple Burden of Malnutrition
TZ	Tanzania
WRA	Women of Reproductive Age
WHO	World Health Organization

1 Introduction

1.1 Triple burden of malnutrition in Sub-Sahara Africa

The burden of undernutrition in sub-Saharan Africa (SSA) has been exacerbated in recent years by an additional significant increase in the prevalence of overweight and non-communicable diseases (NCDs) e.g., diabetes and cardiovascular diseases [1-3]. Increases in overweight are the result of rapid changes in the global food system that make less nutritious food cheaper and more accessible, as well as of the decrease in physical activity, rising among people in urban but also rural areas of most low-income and middle-income countries [4]. The coexistence of undernutrition along with pre-obesity and obesity within individuals, households and populations is defined as the double burden of malnutrition (DBM) [5]. There have been previous indications that undernutrition and overweight are increasingly co-occurring in the same households and becoming a global public health concern [6]. When this double burden is accompanied by micronutrient deficiencies it is referred to as a triple burden of malnutrition (TBM) [7]. The prevalence and associated factors of TBM in the Sub-Saharan African context have not been sufficiently investigated yet, specifically not in rural areas [4,8]. Through the examination of the developing trend of nutrition transition from local food to highly processed food, and the relationship between dietary macro- and micronutrient intake, anthropometrics and anemia, a clearer image of TBM in rural villages of East and South-East Africa can be achieved. According to a meta-analysis involving studies from 23 countries across SSA between 2008 and 2017, anemia was the most common form of household burden of malnutrition, affecting 7 out of 10 households, and DBM/ TBM was present in 8 and 5% of the studied householdes, respectively [9]. A cross-sectional study using data from 22 low- and middle-income countries between 2016 and 2023, showed that 1 out of 10 households suffered from TBM [10]. A former publication using data from rural Tanzania and Kenya in addition to literature review, claimed the parallel occurring of all three types of malnutrition in SSA to the nutrition transition to consuming less fruits and vegetables, but more processed foods and sugar, mainly in comination with teas and drinks [11].

The prevalence of undernourished people in SSA was decreasing from 24.6% in 2005 to 19.4% in 2015, after which it has again been increasing, currently at levels similar to 2005 (24.1%) [12]. At the same time, the prevalence of obese adults in SSA rose from 8.0% in 2012 to 9.25% in 2016. In Tanzania, the prevalence of obesity increased between 2012 and 2016 from 6.9% to 8.4%, while in Mozambique a prevalence increase of obesity from 6.1% to 7.2% was observed between 2012 in 2016 [12]. Globally, and especially in developing countries including East Africa, women are significantly more likely to be pre-obese or obese compared to men [13,14]. A previous study among 510 female and male adults from rural Tanzania reported a prevalence of 20% obesity, of which 94.2% were female [15]. According to their findings the diets consumed were dominated by cereals and staples, with moderate intake of animal-sourced foods, and very little vegetables and fruits, which leads to a high calorie consumption, low in protein, minerals and vitamins. Diets, especially of women living in resource-poor settings are frequently affected by multiple micronutrient deficiencies due to monotonous diets, dominated by the consumption of starchy staple foods, as shown in a previous study from 2017 on 4166 women and another former study from 2010 including dietary intake data of women from 5 different resource poor settings including one from Mozambique [16,17]. A recent study from 2021 on 968 adult female and male Tanzanian teachers stated a prevalence of 72.7% overweight, with a 43% higher occurrence in female compared to male teachers [18]. In 2022, another study on 305 female and male adults from Tanzania showed a prevalence of 68.9% overweight (31.1% pre-obese and 37.8% obese), with a higher prevalence of overweight (74.5%) among women compared to men (54.9%) [19]. A different former study on 1249 female and male adults from Dar es Salaam in Tanzania stated similarly, that overweight was significantly more prevalent in women (24.7%) than in men (9%) [20]. A study from Mozambique, revealed that the prevalence of overweight increased from 18.3% to 30.5 % in women and from 11.7% to 18.2 % in men between 2005 and 2014/2015, being the highest in urban women and lowest in rural men [21]. A study from 2020, used data from Malawi, Kenya, Ghana, and South Africa and showed a higher prevalence of underweight in men compared to women (13.2% vs. 9.4% in Malawi, 13.9% vs. 9.9% in Kenya, 10.4% vs. 7.4% in Ghana and 6.6% vs. 3.2% in South Africa), while the prevalence of overweight (BMI > 25 kg/m^2, 27.3% vs. 12.8% in Malawi, 30.5% vs. 14.5% in Kenya, 37.9% vs. 20.3% in Ghana and 64.0% vs. 38.6% in South Africa) was significantly higher in women in all studied countries [22].

Urban and peri-urban areas in SSA are particularly vulnerable to the nutritional double burden compared with rural areas according to a study from 2016 examining Demographic and Health Surveys (DHS) data of 30 countries in SSA from 2006–2012 including Tanzania and Mozambique. Their findings revealed more than one-quarter of women being overweight with a co-occurring anemia [23]. This increase in overweight is attributed to the changes in lifestyle e.g., availability of cheap ultra-processed food and beverages and low physical activity levels due to increasing urbanization, as it was demonstrated in another study conducted in Tanzania showing that the prevalence of overweight was highest in urban Dar es Salaam compared to rural Handeni and Monduli [24].

However, contrary to the prevailing assumption, a recent meta-analysis using population-based studies of 200 countries between 1985 and 2017 showed that more than 55% of the global rise in mean BMI and more than 80% in some low- and middle-income regions was due to increases in BMI in rural areas, especially for women [25]. In agreement, a study on nutrition transition in rural Tanzania and Kenya highlighted the trending dietary pattern changes dominated by bought and processed foods, high amounts of sugar and low vegetable and fruit consumption, contributing to the increases in the prevalence of overweight and other noncommunicable diseases in the villages [11]. Similarly, a study on 252 rural Tanzanian women aged 16-45 years confirmed the rising nutrition transition in rural areas towards higher fast food purchases characterised by bread and cakes (usually fried in oil), sugar, and sweetened black tea; and loss of local traditional foods and knowledge characterised by the consumption of fruits, vegetables, nuts, fish and starchy plants [26].

Inadequate macro- and micronutrient intake and its consequences, such as anemia, iron and several vitamin deficiencies affect women and men of different age groups in Sub-Sahara Africa [27]. Especially, anemia in women of reproductive age (WRA) was frequently reported in rural areas in Tanzania and Mozambique. A recent meta-study with data between 2005 and 2015 from Tanzanian Demographic and Health Surveys on 23.203 WRA in Tanzania revealed a prevalence of anemia of 44% in non-pregnant women [28]. Another study from 2020 on East-African WRA including 13571 from Mozambique and 13063 from Tanzania revealed a prevalence of anemia of 54% and 45%, respectively [29]. Malnutrition, with its different forms can result from a diet that is deficient in essential macro- and micronutrients, and from the inefficient utilization of available nutrients due to infections e.g., Human immunodeficiency virus (HIV), tuberculosis (TB), and parasitic infestations [30,31]. These infections affect the micronutrient status by decreasing nutrient intake due to loss of appetite, decreased nutrient absorption as a result of intestinal damage and malabsorption, and nutrient losses arising from diarrhea and increased urinary excretion [32]. Micronutrient deficiencies, especially of iron, vitamin A, folate, and vitamin B12, can lead to iron deficiency anemia and other deficiency symptoms such as Xerophthalmia (dry eye syndrome caused by vitamin A deficiency), immunodeficiency, beriberi (vitamin B1 deficiency), low birth weight and stunting in children [33,34]. Although the causes of anemia are multifactorial, dietary nutritional deficiencies and infectious diseases are the leading causes of anemia in SSA [35].

1.2 The Vegi-Leg project

Vegi-Leg is a large collaborative research project aiming to safeguard nutrition security for the local rural population in Tanzania and Mozambique by supporting the development of processing technologies to improve nutrient-quality of food products and ensure their perennial availability. The project focused on nutrient-dense plant foods rich in protein, micronutrients and secondary plant metabolites and therefore selected pigeon peas (*Cajanus cajan*) and African indigenous dark green leafy vegetables as main food items for further processing [36-38]. The project aimed to improve the nutritional status of both female and male farmers and therefore incorporated scientists from Germany and local scientists from Tanzania and Mozambique to achieve the projects' goals. In the frame of Vegi-Leg, this PhD research on nutritional and hemoglobin status in relation to dietary macro- and micronutrient intake of female and male small-scale farmers from Lindi region, Tanzania, and Gurué district, Mozambique examined the prevalence and associated factors of TBM in two neighboring countries in the sub-Saharan African context. Additional data from the two previous projects Scale-N (Scaling Up Nutrition: Implementing Potentials of Nutrition-Sensitive and Diversified Agriculture to Increase Food Security) and Trans-SEC (Innovating Strategies to safeguard Food Security using Technology and Knowledge Transfer), likewise carried out in rural Tanzania to assess the nutritional status, micronutrient intake and TBM, were included.

1.3 The association of micronutrient intake with underweight, overweight, and anemia by season

Smallholder farmers in developing countries, especially in Africa, are often malnourished and suffer from food insecurity [39,40]. Household agricultural production diversity affects the diets and nutrition of people living in rural farming communities in sub-Saharan Africa [41]. Farmers usually consume large parts of their own production, which makes them highly vulnerable to seasonal changes [42]. In rain-fed farming systems, where farmers depend on rainy seasons, the length of the annual lean/ hunger season depends on the extent of self-sufficiency in food progressed in a given year [43]. Thus, low food availability during lean seasons and high market prices of micronutrient-rich food items limits the diets of small-scale farmers in East-Africa and contribute to their malnutrition [44-46]. Further, affordable food items purchased in the markets are usually made of highly processed grains combined with refined oil and sugar, while fruits, vegetables and legumes are either too expensive or not sufficiently available [47]. Recent studies have confirmed that the contribution of market purchases to smallholder diets in sub-Saharan Africa is significantly increasing [48]. According to a study from 2017 in rural

Ethiopia, purchased foods accounted for more than half of all calories consumed during the lean season and more than one-third to total calorie consumption during the main harvest and post-harvest season [49]. The loss of traditional use of plants, as well as changes in culinary tastes and habits contribute similarly to the insufficient micronutrient consumption [50]. Great amounts of 'empty calories' in form of polished maize or rice and too few vegetables are a main cause for the more noticeable multiple burden of overweight, anemia, and MN deficiencies [38]. Diets low in fruits and vegetables and high in sodium and sugar have been reported to be the most common specific dietary risks for noncommunicable diseases e.g., diabetes, hypertensive heart disease, or stroke [51,52]. Therefore, despite the rich local food biodiversity of indigenous edible plants, rural households rely on few food items that do not sufficiently cover their micronutrient needs due to limited awareness [53].

1.4 Mid-upper arm circumference as an alternative marker to detect malnutrition

For individual assessments of body composition, anthropometry is being commonly measured by weight and height to calculate the body mass index (BMI; ratio of height and weight, expressed as kg/m^2) [54]. Although the BMI still remains a valid tool and the gold standard for epidemiological studies on assessment of nutritional status, especially at community levels, several difficulties can be encountered during its use. Measuring weight and height to calculate the BMI during larger studies particularly in resource-poor settings and rural areas, where equipment (e.g., scales, stadiometers) is limited, can represent difficulties in assessing the nutritional status of a study population. Thereupon, a simpler and faster alternative tool to BMI could support clinical assessments of malnutrition, and enhance surveillance of under- and overnutrition [55,56].

The use of mid-upper arm circumference (MUAC), which is the circumference of the left arm midway between the tip of the elbow and the tip of the shoulder, can screen and assess malnutrition by detecting underweight as well as pre-obesity and obesity [57]. The measurement of MUAC requires minimal equipment and calculations i.e., tapes graduated in millimeters or color coded representing the BMI categories (red, yellow and green) as compared to weight and height measurements for calculation of body mass index (BMI) [58]. Increasingly, MUAC is being used to assess nutritional status and determine eligibility for nutrition support among children, adolescents and adults in low-resource settings, especially among pregnant women, where BMI measurements are no longer accurate in comparison to MUAC [59-61]. Numerous studies have shown that MUAC correlates well with BMI in adult populations e.g., a study on 226 adult hospitalised patients showing that both BMI and MUAC were equivalently able to identify 21% of participants as underweight or malnourished, and

39% as overweight [58]. Similarly, a study on 650 Bangladeshi adults showed strong positive correlations between MUAC and BMI for both females and males [61]. A prior study on 1165 pregnant women with diverse ethnic characteristics confirmed the strong correlation between BMI and MUAC, approving the advantages MUAC has over BMI due to its simplicity of application and capability of tracking nutritional status during pregnancy [62]. To date, however, several proposed MUAC cut-offs for detecting undernutrition in adolescents and adults are available but have not yet been established, while few cut-off proposals are available for pre-obesity and obesity. The actual trend of an increasing prevalence of overweight, combined with an insufficient intake of micronutrients and associated high prevalence of anemia and micronutrient deficiencies in rural areas of Africa requires prompt and reliable tools to measure the extent of existing malnutrition [63,64]. Therefore, the establishment of standardised MUAC cutoffs for both underweight as well as overweight among adolescents and adults could help expand the understanding and detection of community malnutrition [58,59].

1.5 Evaluation of a food-group based algorithm (CIMI) to assess dietary nutrient intake of women in rural areas in Tanzania

Early and fast detection tools of different forms of dietary malnutrition are essential for tailored interventions. Commonly used food intake screening tools e.g., Food Frequency Questionnaire (FFQ) and Household Dietary Diversity Score (HDDS) are just proxy-indicators, not suitable to calculate individual quantitative intake of single macro- and micronutrients. In contrast, 24-hour recalls provide quantitative information of daily consumed macro- and micronutrients, however data collection can be complex and time-consuming.

The algorithm CIMI (Calculator of Inadequate Micronutrient Intake), which has been developed in a collaboration between day-med-concept GmbH (dmc) in Berlin and the University of Hohenheim, was therefore designed to collect and analyse individual macro- and micronutrient intake data in a faster and easier way. CIMI identifies macro- and micronutrient gaps, by merging comparable food items to food groups and then estimating an average for the macro- and micronutrient intake of each whole food group. Dietary intake data entered into CIMI are compared to the globally recognised Recommended Daily Intakes (RDI) of macro- and micronutrients issued by the Food and Nutrition Board of the National Academies of Sciences Engineering, and Medicine [65]. This is performed directly during the interview, enabling the interviewer to instantly inform the participant about the results of his/her nutrition and diet analysis and about current nutrient deficiencies. This may increase the motivation of the interviewee to provide correct and complete data, and enables faster action and intervention in case of malnutrition. Former studies in Indonesia, Ghana and Ethiopia already showed, that the food group-based approach of CIMI produces valid results of macro- and micronutrient intake of subjects of different age and sex [66-69]. In Indonesia, comparisons between CIMI and NutriSurvey, a well-established program for nutrition calculations and surveys, on the average intake of energy and other nutrients of 118 children and 124 women revealed similar results. The study confirmed the approach of CIMI in using the dietary pattern of certain populations as a database in form of food grouping, to simplify the work to calculate energy and nutrient intakes [66]. Likewise, the use of CIMI on 126 households in one rural and two urban communities in Ghana provided similar results to NutriSurvey, while assuring fast and valid dietary assessments and real-time surveys [69]. The validation of CIMI-Ethiopia using 24-hour recalls of 578 WRA in postharvest dry and lean wet seasons showed high positive correlations between CIMI and NutriSurvey confirming CIMI-Ethiopia to be a valid tool for estimating nutrient intakes at individual levels, while detecting and highlighting seasonal variations in micronutrient intake e.g., declining iron and zinc intake in the lean season [68]. Therefore, this study aimed to examine the accuracy of the CIMI algorithm in comparison to NutriSurvey using anthropometric and nutritional consumption data from Tanzania. Data of 1010 women from rural villages of the two districts Chamwino and Kilosa of the Dodoma and Morogoro region, collected during two cross-sectional studies within the two research projects Scale-N and Trans-SEC were included in this study.

1.6 Objectives of the thesis

The present work was carried out within the framework of the project Vegi-Leg to examine the nutritional and hemoglobin status in relation to dietary micronutrient intake of female and male small-scale farmers from Tanzania and Mozambique. This work aims to map and understand the contextual factors of different forms of malnutrition persisting in rural villages of two neighbored countries of South and South-East Africa identifying nutritional gaps leading to a TBM. Data on anthropometrics, hemoglobin and dietary intake of the enrolled farmers were analysed and additionally compared between seasons. MUAC as an alternative anthropometric measurement tool to the BMI is analysed and evaluated in rural settings. Finally, the food-group based CIMI algorithm is tested for Tanzania in comparison to 24-hour recalls entered into NutriSurvey.

The specific objectives of the present study were to analyse and evaluate:

(1) The nutritional status among the enrolled farmers using anthropometrics (BMI and MUAC), hemoglobin status, and diet regarding macro- and micronutrient intake.

(2) Associations between hemoglobin, BMI and diet and seasonal effects.

(3) Assessment of MUAC as alternative nutritional marker to BMI for the detection of underweight, as well as of overweight and obesity.

(4) Assessment of food-group based CIMI algorithm as an alternative real-time survey analysis tool compared to conventional (detailed) 24-hour recalls.

2 Methodology of the study

2.1 Study sites and inclusion criteria of study population

The Vegi-Leg study took place in two countries in East and South-East of Africa, namely Tanzania and Mozambique. In Tanzania, Vegi-Leg was carried out in the two districts Nachingwea (Mitumbati village) and Ruangwa (Mibure village) of the Lindi region, while in Mozambique the study took place in Gurué district in Zambézia province (Ruace and Nicoropale villages). The projects Scale-N and Trans-SEC were implemented in four rural villages of Chamwino district in Dodoma region (Mzula, Chinoje, Ilolo and Idifu villages) and four rural villages in Kilosa district, Morogoro region (Tindiga, Muhenda-Kitunduweta, Changarawe and Ilakala villages) in Central Tanzania (Figure 1 and Figure 2).

Figure 1: Map of study sites in Tanzania:

http://karteplan.com/tansania/gro%C3%9Fe-detaillierte-karte-von-tansania.html

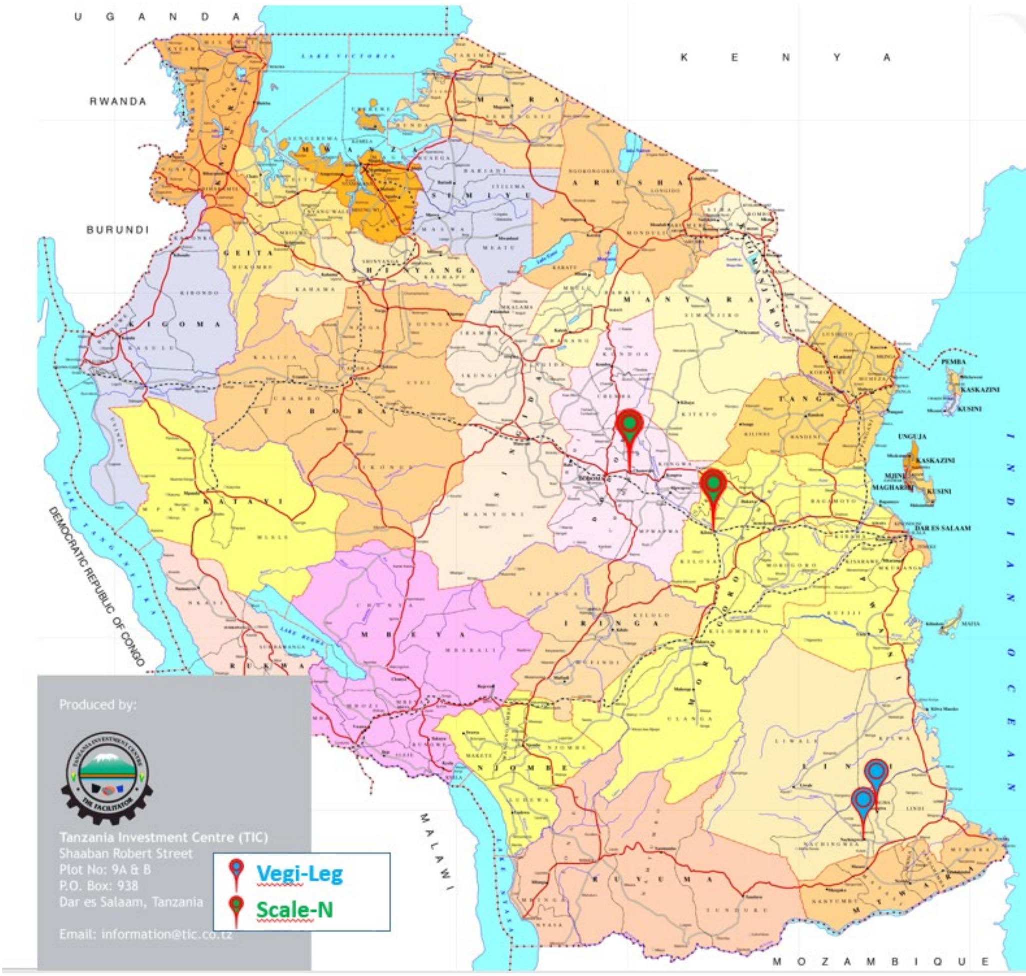


Figure 2: Map of Vegi-Leg study sites in Mozambique:

https://www.missionshub.org/gospel-africa/ch%C3%A1-guru%C3%A9

Both Vegi-Leg case study regions consisted of households engaged in subsistence farming or small-scale agriculture including the cultivation of pigeon peas to generate income, with a substantial portion of the food consumed in the household. Similarly, the two further projects scale-N and TransSec were primarily concerned with subsistence farmers in Tanzania. The study regions of the present projects suffer from high levels of malnutrition. The anemia rates in WRA of Lindi, Morogoro and Dodoma are at 48.9%, 47.5% and 30.6% respectively, while in Zambézia province 61.7% of women were anemic according to the national demographic health surveys of 2011 [70,71].

The cross-sectional baseline study of the Vegi-Leg project was carried out in July to August 2019 and a follow-up study in the same villages of Mozambique and Tanzania, was carried out in December 2019 and March 2020, respectively. Inclusion criteria for the Vegi-Leg project was that the female and male farmers enrolled had grown pigeon peas in the last 3 years. The study procedure included collection of socio-demographic data, anthropometric and hemoglobin measurements, as well as dietary intake assessments in the form of Household Dietary Diversity Scores (HDDS), Food Frequency Questionnaires (FFQ) and 24-hour dietary food intake recalls of the enrolled farmers. The baseline study of Scale-N was conducted from

July to August 2016, and the baseline study of Trans-SEC from January to April 2015. In Vegi-Leg anthropometric, hemoglobin and dietary intake data of 669 farmers from Tanzania (362 females and 307 male) and 857 farmers (488 females and 369 male) from Mozambique and therefore a total of 1526 pigeon pea farmers were collected. Additional anthropometric, hemoglobin and data on serum vitamin A (retinol binding protein), iron status (serum ferritin, soluble transferrin receptor) and serum zinc of 666 female farmers from the project Scale-N were included for the MUAC analysis, and for the evaluation of the CIMI algorithm in combination with anthropometric and dietary intake data of 344 farmers from the project Trans-SEC.

The surveys of the projects Vegi-Leg (NIMR/HQ/R.8a/Vol.IX/3040 in TZ and IRB00002657, Ref 370/CNBS/19 in MZ), Scale-N (NIMR/HQ/R.8a/Vol. IX/2226) and Trans-SEC (NIMR/HQ/R.8a/Vol.IX/2226) were carried out according to the guidelines laid down in the 'Declaration of Helsinki' and ethically approved and reviewed by the National Institute for Medical Research in Dar es Salaam, and the National Bioethics Committee for Health of Mozambique.

The Vegi-Leg surveys were additionally approved by the Ministry of Health, Community Development, Gender, Elderly and Children in Dodoma, Tanzania, While the the Scale-N survey was likewise approved by the Ethics Committee Landesärztekammer Baden-Württemberg, Stuttgart, Germany (F-2016-049). Written informed consent was obtained from all female and male farmers.

2.2 Anthropometry

Weight, height and mid-upper arm circumference (MUAC) were measured using electronic or mechanical floor scales (Seca 874 in Tanzania, Seca 750 in Mozambique, Seca GmbH & Co KG Hamburg, Germany), a wooden (UNICEF) or plastic stadiometer (seca 213, Seca GmbH & Co KG Hamburg, Germany), and a standard MUAC tape (UNICEF in Tanzania or Seca 201 in Mozambique), respectively. Weight was recorded to the nearest 0.1 kg, while height and MUAC were measured to the nearest 0.1 cm. MUAC, which is the circumference of the arm midway between the tip of the elbow and the tip of the shoulder, was measured on the left arm of the farmers. Body mass index (BMI) was calculated from weight and height measured at admission; cut-offs for underweight (<18.5 kg/m^2), overweight (≥25 kg/m^2) and obesity (≥30 kg/m^2) were used according to WHO instructions [72]. Anthropometry data were recorded on paper in the field, then entered into excel and SPSS.

2.3 Hemoglobin status

Hemoglobin concentrations of the female and male farmers were measured at study sites and subsequently recorded on paper. During the surveys, a drop of finger prick blood (taken by trained technicians) filled in microcuvettes and placed in the hemoglobinometer (HemoCue Hb 201+, HemoCue AB, Ängelholm, Sweden.) was used for immediate reading [g/dL]. Anemia was defined as follows: men, non-pregnant and pregnant women with hemoglobin concentrations lower than 130 g/L, 120 g/L and 110 g/L, respectively [73].

2.4 Dietary Intake assessment: HDDS, FFQ and 24-hour recalls

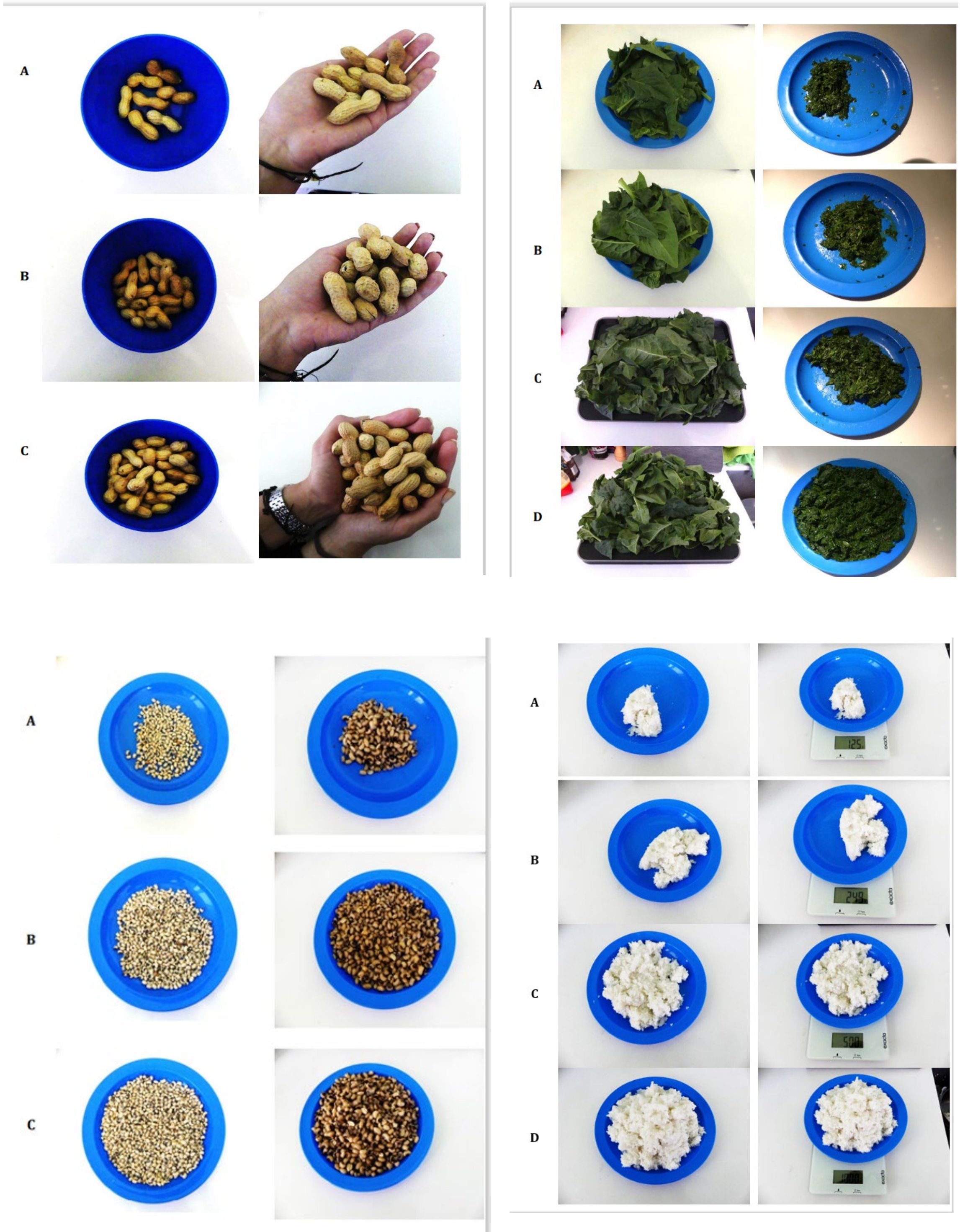
To analyse the dietary intake of enrolled female and male farmers, Household Dietary Diversity Scores (HDDS), Food Frequency Questionnaires (FFQ) and 24-hour recalls were conducted. The HDDS serves as a measurement tool for individual household food access, since previous research has shown that dietary diversity can be directly related to food security [74,75]. The standardised HDDS developed by FAO and FANTA consists of 12 food groups, and was modified to 16 food groups for a more accurate and specific assignment of the food groups responsible for vitamin A and iron consumption. [76]. For the analysis of the Vegi-Leg data and due to limited food availability in the study region, the following groups of the modified HDDS from the FAO were combined into new groups: ‘vitamin A rich fruits’ and ‘other fruits’ into the food group ‘fruits’; ‘organ meat’ and ‘flesh meat’ into ‘organ and flesh meat’ and ‘eggs’ and ‘milk and milk products’ into ‘eggs and milk products’. The food group ‘bread and similar products’ was added to the questionnaire, since it is common to deep-fry bread in oil in the respective study sites; we separated this food group from conventional cereals, which finally resulted in a Vegi-Leg-adapted HDDS of a total of 14 relevant food groups. Each participant was asked if he/ she or other persons in the household consumed food items included in the 14 different food groups in the last 24 hours. The score was calculated from the sum of the indicated 14 possible food groups; thus, a score from 0 to 14 was created. The following 14 food groups were assessed within the HDDS: 1. ‘cereals’, 2. ‘bread and similar products’, 3. ‘starchy plants’, 4. ‘legumes and pulses’, 5. ‘green leafy vegetables’, 6. ‘other vegetables’, 7. ‘fruits’, 8. ‘nuts and seeds’, 9. ‘oil and fats’, 10. ‘fish and seafood’, 11. ‘flesh meat and organ meat’, 12. ‘eggs, milk and milk products’, 13. ‘sugar and sweets’ and 14. ‘coffee, tea and alcoholic beverages. The Vegi-Leg HDDS was repeated in the villages of Mozambique and Tanzania during the rainy season in December 2019 and March 2020 respectively, to compare dietary diversity patterns in the different seasons.

The Food Frequency Questionnaire (FFQ) in this survey consisted of a list of available foods and beverages indicating their usual frequency of consumption per week. Hence, a list of available foods in the study areas was conducted. The list of foods and beverages was structured into 14 different food groups similar to the HDDS and contained a total of 108 different food items or beverages [Table A1]. The selection of the foods reflected the common food habits in the study sites. Based on the FFQ data, the individual weekly consumption from 14 different food groups was calculated. The FFQ was repeated in the villages of Tanzania at the end of the rainy season (March 2020) to compare weekly consumption patterns in the two different seasons.

For the 24-hour dietary recalls, each participant was asked to list all estimated amounts of all different foods and beverages consumed within the previous 24 hours, which were then recorded in grams either using tablets during the Vegi-Leg project or on paper during Scale-N and Trans-SEC projects [77]. A booklet with food photographs in different portions shown in typical household utensils and in handful of portions was used in the Vegi-Leg project to assist the farmers in estimating the exactly consumed portion sizes [78]. Since food habits vary between (and within) countries, the food photographs used in the Vegi-Leg study represented the most important local food items and dishes of the respective study sites. The food photographs were produced in Germany before the study. Commonly consumed staple foods and sauces (or stews), which were considered feasible to cook in the test setting were chosen to be presented in the photographs. The choice of the foods was also discussed with local women/ colleagues of both countries. The foods chosen to be photographed and tested were: (i) groundnuts (peeled and unpeeled); (ii) cashews; (iii) sugar; (iv) thick maize porridge (ugali in Tanzania/ xima in Mozambique); (v) thick millet porridge; (vi) thin maize porridge (uji in Tanzania); (vii) green leaves (fresh and cooked); (ix) okra; (x) tomatoes; (xi) onions; (xii) rice; (xiii) cowpeas (dry and cooked), and (xiv) pigeon peas (dry and cooked).

Three different portion sizes (‘small handful’, ‘one handful’ and ‘2 hands full’) of groundnuts, cashews, maize and millet porridge, cowpeas and pigeon peas were weighed and placed on the kitchen scale or plastic bowls similar to the ones available in the villages [Table A2]. Rice and dark green leafy vegetables were photographed in 4 different portions. The portion sizes were decided based on the observations during previous field visits and previous 24-hour recalls from the Scale-N project in rural Tanzania. Thick maize porridge is always served in the shape of balls, but the size of the ball may vary depending on the cook. Different ball sizes were portrayed in each of the three porridge photographs in relation to the size of a hand and a common plastic dishware. The photographs were taken with a digital camera using a tripod and the camera angle was set on about 45° [Figure 3].

Figure 3: Examples of different food portions from the Vegi-Leg food photographs booklet



2.5 Food-group based algorithm to assess dietary nutrient intake (CIMI)

To test the CIMI algorithm, data from two cross-sectional studies within the two projects Scale-N and Trans-SEC were used. Socio-demographic, anthropometric and nutritional data from 1010 women, 344 from Trans-SEC and 666 from Scale-N were available. The Scale-N study included additional data on serum vitamin A (retinol binding protein), iron status (serum ferritin, soluble transferrin receptor) and serum zinc, which allowed anemia and micronutrient deficiencies to be identified in the participating women [79,80].

Different to classic 24-hour recalls, CIMI evaluates the consumed foods by categorizing them into food groups to facilitate data input. Consumed foods in the two districts Chamwino and Kilosa were split into 23 different food groups according to available FFQ data of the Trans-SEC sub-sample. Composition of the food groups and contribution of single foods to the different groups are shown in [Table A3]. The nutrient profiles of each food group were determined by calculating the average amount of nutrients with regard to the proportionate consumption of the food items in the target region, that are aggregated in a specific food group. This was achieved using the following summation formula:

$$\sum_{k=1}^{n} c_k \cdot n_k = c_1 \cdot n_1 + \cdots + c_n \cdot n_n \quad ,$$

Σ is the sum of the average nutrient content of a food group, c_k is the amount of an individual food item in the food group consumed and n_k is the nutrient content of the individual food item.

The 24 hour-recalls were used for the in-depth evaluation of nutrient intake calculation by the CIMI algorithm, in comparison to NutriSurvey.

The prevalence of anemia and micronutrient deficiencies in serum served as an additional marker to evaluate CIMI in comparison to Nutrisurvey in association with dietary micronutrient deficiencies (nutrient intake below the RDI). Iron deficiency was defined as ferritin <12 µg/L and/or soluble transferrin receptor (sTfR) >8.5 mg/L, while total body iron stores (IST) were calculated using SF and sTfR in an equation processed by Cook et al.: body iron (mg/kg) = -[log10(sTfR x 1000/SF) – 2.8229]/ 0.1207 [81,82]. Retinol <1.05 µmol/L was considered indicative of low vitamin A status, while serum zinc <0.66 mg/L was used to indicate low/deficient zinc status [73,83].

2.6 Data collection, analysis and statistics

Descriptive analysis of demographic, anthropometric and hemoglobin data of female and male farmers, as well as detailed nutritional behaviour characteristics assessed by HDDS, FFQ and 24-hour recalls at the baseline (July to August 2019) and follow up studies of the Vegi-Leg project were conducted. The HDDS was repeated with the same households from the baseline study in follow up studies in both countries, in Mozambique in December 2019 and in Tanzania in March 2020. The FFQ together with hemoglobin measurements were repeated during the follow-up study in Tanzania in March 2020 during the rainy season. Anthropometry and hemoglobin measurements of the enrolled farmers in Vegi-Leg, Scale-N and Trans-Sec were measured in the field and recorded on paper. Vegi-Leg dietary intake data were collected via tablets in the field and were uploaded daily to a server using the program Open Data Kit (ODK)-Ona in Lindi and ODK-KoboCollect in Gurué. Data were checked and entered in Microsoft Excel, then merged into a SPSS (Statistical Package for the Social Sciences) database developed by IBM for data management, advanced analytics and multivariate analysis. Dietary data from the earlier Scale-N and Trans-SEC projects were collected on paper in the field and manually transferred directly into SPSS afterwards.

Demographic characteristics, anthropometrics, and blood concentrations (hemoglobin, retinol, zinc and iron status), and the calculated macro- and micronutrients intake of the farmers were described using medians and interquartile ranges (25% and 75% percentiles) for continuous variables and percentages(numbers) for categorical and binary data. Socio-demographic data, micronutrient intake and frequency and amount of consumed food groups were compared between female and male farmers and different study regions in Tanzania and Mozambique using the Kruskal–Wallis test with pairwise multiple comparisons, Mann-Whitney-U tests or post-hoc Dunn-Bonferroni and Chi-Square tests (prevalence), as appropriate.

For , multiple regression analysis, dietary intake data on vitamin A, iron and zinc were transformed using square root (SR) or logarithmic (LN) transformation to achieve normal distribution. For each of the two study sites, multiple linear regression models with a forward stepwise approach were applied to identify predicting food groups (e.g., grams of leafy vegetables or legumes) for vitamin A, iron and zinc intake. In addition, the percentage contribution of the respective food groups to vitamin A, iron and zinc intake was calculated as the product of frequency and average consumption of the food groups.

The continuous normal distributed variables (e.g., HDDS) were described by their mean (SD) and range, while skewed variables (e.g., FFQ) were presented by their median (interquartile range) and range (minimum-maximum). Comparing data from the baseline survey with data from the follow-up, the related-samples Wilcoxon signed ranks test (continuous data) and the McNemar test (for prevalence) were used. For the representation of seasonal differences of the FFQ and the HDDS a ‘trend’ was displayed. The trend was created by generating the difference of the respective value (median or prevalence) from the follow-up survey and the belonging value (median or prevalence) of the baseline survey. Correlations between hemoglobin and FFQ data were assessed using the Spearman correlation coefficients. Comparisons between CIMI and NutriSurvey were assessed by differences in means, medians, bivariate correlation (Pearson) and Bland-Altman analysis (Bland-Altman plots). All statistical analyses were conducted using SPSS version 20; two-tailed P values <0.05 were considered as statistically significant.

3 Results

3.1 ''Anthropometrics, hemoglobin status and dietary micronutrient intake among Tanzanian and Mozambican pigeon pea farmers''

Laila Eleraky, Ramula Issa, Sónia Maciel, Hadijah Mbwana, Constance Rybak, Jan Frank, Wolfgang Stuetz (2022): This article has been published in: *Nutrients* 2022, 14(14), 2914.

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Anthropometrics, Hemoglobin Status and Dietary Micronutrient Intake among Tanzanian and Mozambican Pigeon Pea Farmers

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Abstract: Inadequate consumption of micronutrient-dense and protein-rich foods such as vegetables, legumes and meat is an important contributing cause for anemia and deficiencies of vitamin A and iron in rural communities of Tanzania and Mozambique. A cross-sectional study was conducted to assess the nutritional status (anthropometrics and hemoglobin) and diets in particular micronutrient intake of female and male pigeon pea farmers from Lindi, Tanzania, and Gurué, the Zambézia province of Mozambique. A total of 1526 farmers (669 from Tanzania, 857 from Mozambique) were studied, of whom 16% were overweight and 35% were anemic. The highest prevalence of overweight and anemia, at 35% and 48%, was observed in Tanzanian and Mozambican women, respectively. Overall, only a small proportion of women and men reached the recommended daily dietary intake of vitamin A (10%), iron (51%) and zinc (44%). Multiple regression models revealed that dark green leafy vegetables (DGLVs) highly predicted vitamin A intake, whereas legumes in Tanzania and starchy plants in Mozambique were actually the dominant sources of vitamin A. Cereals covered over half of the iron and the zinc intake in both countries. An increased consumption of micronutrient-rich DGLVs and legumes, while reducing the high amounts of refined maize or polished rice, is suggested to counteract the high prevalence of anemia and overweight among smallholder farmers in East and South Eastern Africa.

Keywords: legumes; dark green leafy vegetables; Tanzania; Mozambique; anemia; micronutrient intake; micronutrient status; overweight; small-scale farmers

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1. Introduction

Anemia is a worldwide problem that is highly prevalent in developing countries, especially in women of reproductive age [1]. Infectious diseases, poor water hygiene, and the low bioavailability of dietary iron from specific (plant-based) foods are the main contributing factors for a high prevalence of anemia [2]. Rural areas of Sub-Saharan Africa are among the most affected regions with anemia and deficiencies of vitamin A, iron and zinc [3–5]. Malaria infection was positively associated with having anemia according to a study on women of reproductive age (15–49 years) enrolled in the demographic and health surveys of 27 countries in Sub-Saharan Africa, conducted between 2010 and 2019 [6]. Blood loss caused by worm infections including hookworm, whipworm and schistosomiasis leads to direct iron-deficiency anemia [7]. A previous case–control study among 191 anemic and 382 non-anemic pregnant women from Ethiopia revealed anemia as almost 6-fold more common among pregnant women who had intestinal helminthic infection than those with no intestinal helminthic infection [8]. In the Lindi district of Tanzania, nutritional anemia and iron deficiency were associated with a monotonous cereal and vegetable-based diet, as well as parasitic and malaria infection [9]. A cross-sectional study of more than 500 female adolescents from rural and urban Mozambique examining their biochemical status showed that the prevalence of deficiencies and dietary intake revealed almost every second female as anemic (42.2%) on account of iron depletion and have low serum zinc and vitamin A deficiency due to diets rich in carbohydrates and low in protein, fat and micronutrients [10].

A general trend of nutrition transition in low-income countries regarding a transformation in the diets towards less healthy ultra-processed foods rich in refined carbohydrates, fat and sugar led to the emergence of 'a double burden of malnutrition' by means of both undernutrition and overweight [11]. In the case of an additional micronutrient deficiency, one defines a 'triple burden of malnutrition', namely undernutrition, overweight and micronutrient deficiency in the same population [12]. The persistent dietary deficiencies of particularly vitamin A, iron and zinc alongside emerging overweight occurring within the same community have already been proven many times, as illustrated in a study of adolescents from four rural and urban settings in Africa and India [13]. In the latter study, both undernutrition and overweight were present in all settings and adolescents reported low intakes of micronutrient-rich fruits and vegetables, but high intakes of sweets and sweetened soft drinks. The prevalence of overweight and obesity increased significantly between the years 1991 and 2014 according to demographic and health survey data of women 15–49 years old from 24 African countries, including Tanzania and Mozambique [14]. A survey from Sub-Saharan Africa including 276 adults from Tanzania revealed three in four participants from Tanzania as overweight or obese and women as more affected by overweight than men [15]. The double burden of malnutrition characterized by the co-existence of undernutrition along with overweight and even obesity has emerged as an important health problem in Sub-Saharan Africa and is directly linked to the increase in ultra-processed food consumption [16].

A higher consumption of micronutrient-rich dark green leafy vegetables (DGLVs) and protein-rich legumes such as pigeon peas (*Cajanus cajan*) would positively contribute to a healthy diet, as shown in Botswana [17]. Pigeon peas are an excellent source of proteins, and also provide high concentrations of minerals including iron and zinc [18–20]. A higher consumption of DGLVs was associated with higher hemoglobin and a lower prevalence of vitamin A and iron deficiencies in resource-poor communities, as shown in a previous study on 666 women from different areas of rural Tanzania [21]. The Vegi-Leg project, a multidisciplinary study supported by the German Federal Ministry of Food and Agriculture (BMEL), operates in Lindi, South Tanzania, and in Gurué, the Zambézia province of Mozambique, among female and male pigeon pea farmers. The project aims to improve the nutritional status of both female and male farmers by introducing tailored, nutrition-sensitive interventions including improved processing technologies, e.g., suitable drying techniques for pigeon peas and dark green leafy vegetables to ensure year-round food security. The objective of the baseline survey held in 2019 was to assess nutritional status by measuring anthropometry and hemoglobin and to identify nutritional gaps, by calculating dietary micronutrient intake among the enrolled female and male farmers in the study regions.

2. Materials and Methods

2.1. Study Population and Field Procedure

The baseline study of the Vegi-Leg project was carried out in July to August 2019 in the Mitumbati and Mibure villages in Lindi, Southern Tanzania and in the Nicoropale and Ruace villages of Gurué district, in the Zambézia province, Central Mozambique. Inclusion criteria for the Vegi-Leg project was that the farmers had grown pigeon pea in the last 3 years. The study population were female and male small-scale pigeon pea farmers in regions where a high prevalence of anemia (women from Lindi in Tanzania 48.9% and from Zambézia in Mozambique 61.7%) was previously reported [22–24].

The study procedure included anthropometric and hemoglobin measurements, as well as 24 h dietary food intake recalls of the farmers.

The surveys were carried out according to the guidelines laid down in the 'Declaration of Helsinki' and approved by the National Institute for Medical Research, Dar es Salaam and the Ministry of Health, Community Development, Gender, Elderly and Children in Dodoma, Tanzania (NIMR/HQ/R.8a/Vol.IX/3040), and ethically reviewed by the National Bioethics Committee for Health of Mozambique (IRB00002657, Ref 370/CNBS/19). Written informed consent was obtained from all farmers.

2.2. Anthropometric and Hemoglobin Measurements

Weight, height and mid-upper arm circumference (MUAC) were measured using electronic or mechanical floor scales (Seca 874 and Seca 750, Seca GmbH & Co KG, Hamburg, Germany), a wooden (UNICEF) or plastic stadiometer (Seca 213, Seca GmbH & Co KG, Hamburg, Germany), and a standard MUAC tape (UNICEF in Tanzania or Seca 201 in Mozambique), respectively. Weight was recorded to the nearest 0.1 kg, while height and MUAC were measured to the nearest 0.1 cm. MUAC was measured on the left arm. Body mass index (BMI) was calculated from weight and height measured at admission; cut-offs for underweight (<18.5 kg/m^2), overweight (≥ 25 kg/m^2) and obesity (≥ 30 kg/m^2) were used according to WHO and FANTA instructions [25,26]. MUAC cut-offs demonstrating underweight at <24 cm, overweight at ≥ 30 cm and obesity at ≥ 33.5 cm were set based on suggestions from recent studies [27,28].

Hemoglobin concentrations were measured at the study site using capillary blood sample obtained from a finger prick by using a sterile lancet measured into a hemoglobinometer (HemoCue Hb 201+, HemoCue AB, Ängelholm, Sweden). For quality control, a "HemoTrol" quality control solution (normal, 12 g/dl, Eurotrol, Elizabethtown, KY, USA) was measured daily for the 23 days (5–8 times per day), giving an overall mean (SD) of 12.2 (0.32) g/dl and a coefficient of variation (CV) of 2.6%. Anemia was defined as hemoglobin <120 g/L for non-pregnant, <110 g/L for pregnant women and <130 g/L for men [29].

2.3. Assessment of Dietary Intake

Information on the amount of consumed food items was collected using 24 h food recalls. For the 24 h recalls, each interviewee was asked to precisely name all foods and amounts consumed in the past 24 h. Photos of portion sizes using typical household utensils in the form of booklets were prepared and used to estimate the amounts consumed and subjects were asked to indicate if the named amount was consumed alone or shared in the household. The macro- and micronutrient intake of the female and male farmers was calculated using the Tanzanian Food Composition Tables [30] and a Mozambican food database from a former study in the same region, the Zambézia province [31], respectively. Macro- and micronutrient food values of those food databases were imported into NutriSurvey software (www.nutrisurvey.de) (accessed on 29 February 2020) [32]. The NutriSurvey database was completed with a Kenyan food database, as well as micronutrient concentrations of DGLVs previously analyzed at the university of Hohenheim [33].

The calculated intakes of macro and micronutrients were compared with daily recommended dietary intakes according to sex, age and pregnancy status [34,35]. Individually assessed food items (e.g., grams of eaten mango or cassava) were further merged to 14 food groups to assess their frequency and amount consumed and to finally elucidate different food groups responsible for iron, vitamin A, and zinc intake.

The 14 food groups are defined as follows: 1. 'Cereals': maize, rice, sorghum, and millet ('ugali' and 'uji'); 2. 'Bread and similar products': dough made from wheat or rice fried or baked in oil (bread, chapatti, noodles, African donuts, 'bhajia', and half-cake); 3. 'Starchy plants': white potatoes, sweet and Irish potatoes, cassava, plantain, yam, and taro; 4. 'Legumes': pigeon peas, cowpeas, kidney beans, lentils, chickpeas, and bambara nuts; 5. 'DGLVs': cowpea leaves, spinach, amaranth leaves, cassava leaves, sweet potato leaves, mlenda, lettuce, and pumpkin leaves; 6. 'Other vegetables': tomatoes, eggplant, carrots, onions, okra, cabbage, pumpkin, and mushroom; 7. 'Fruits': mango, papaya, banana, jackfruit, avocado, orange, lemon, and mandarin; 8. 'Nuts': groundnuts, cashews, coconut, and sesame; 9. 'Oil and fat': sunflower oil, vegetable oil, palm oil, and butter; 10. 'Fish': fresh or dried fish, sardines, fried fish, tuna, and shrimp; 11. 'Meat': beef, chicken, duck, rat, goat, and pork; 12. ' Eggs and diary': egg pancakes, eggs, milk, and yoghurt; 13. 'Sugar and sweets': sugar, sugarcane, carbonated drinks, cola, and sweetened juices; 14. 'Beverages': tea and beer.

2.4. Statistical Analysis

Demographic characteristics, anthropometrics, hemoglobin, and the calculated macro- and micronutrients intake of the farmers were described using medians and interquartiles (25% and 75% percentiles) for continuous variables and percentages for categorical data. Socio-demographic data, micronutrient intake and frequency and amount of consumed food groups were compared between female and male farmers of the two different study regions in Tanzania and Mozambique using the Kruskal–Wallis test with pairwise multiple comparisons or the Chi-Square test, as appropriate.

For further analysis regarding multiple regression, dietary intake data on vitamin A, iron and zinc were transformed using square root (SR) or logarithmic (LN) transformation to achieve normal distribution. For each of the two study sites, multiple linear regression models with a forward stepwise approach were applied to identify predicting food groups (e.g., grams of leafy vegetables or legumes) for vitamin A, iron and zinc intake. In addition, the percentage contribution of the respective food groups to vitamin A, iron and zinc intake was calculated as the product of frequency and average consumption of the food groups.

All statistical analyses were conducted using SPSS Version 20; p values < 0.05 were considered as statistically significant.

3. Results

A total of 1526 farmers—669 from Lindi, Tanzania and 857 from Gurué, Mozambique—were successfully enrolled in the Vegi-Leg baseline study. Socio-demographic data, anthropometrics and hemoglobin concentrations of the female (55.7%) and male (44.3%) farmers, separated by region (Lindi) or district (Gurué) of the respective countries, are summarized in Table 1. Female and male farmers from Tanzania were significantly older (+7 years for females and +5 years for males) than those from Mozambique.

Weight and height were higher among male compared to female farmers in both countries, but BMI, MUAC, and the prevalence of overweight and obesity were significantly higher in women (in both countries) than in men. In Tanzania, one in three women was overweight and one in ten was obese. Underweight only played a role among men in both countries, as the prevalence of underweight was higher than the prevalence of overweight. In total, 35% of the farmers studied were anemic. The prevalence of anemia was significantly higher in women than in men and overall, significantly higher in Mozambique than in Tanzania: each second woman in Mozambique and each third woman in Tanzania was anemic. Self-reported malaria was particularly high in Mozambique: one in two women and one in three men reported having malaria within the past 90 days; whereas one in six female or male farmers in Tanzania reported having malaria within the past three months.

The farmers' reported dietary intake of energy, protein, fat, carbohydrates, vitamins and minerals of the previous 24 h in relation to the D-A-C-H [34] and FAO/WHO [35] recommended daily intakes (RDI), by country and sex are shown in Table 2. The reported food intake of male farmers from Tanzania revealed the highest energy, protein, fat and carbohydrates content and was significantly higher than that of female farmers in Tanzania and the farmers in Mozambique. Overall, farmers from Tanzania had a better protein intake; three out of four farmers in Tanzania achieved the RDI (75%), whereas only one out of two farmers achieved the RDI (50%) in Mozambique. Generally, the farmers in

Tanzania were better supplied with vitamin A than the farmers in Mozambique; however, only the minority of farmers (5% in male farmers in Mozambique to 14% in male farmers in Tanzania) reached the daily intake recommendations for vitamin A. Even fewer farmers from both countries reached the recommended values for daily vitamin E intake (5–8%).

Table 1. Characteristics and anthropometrics of the study population.

	All (N = 1526)	**TZ-F (N = 362)**	**TZ-M (N = 307)**	**MZ-F (N = 488)**	**MZ-M (N = 369)**
Age [years] [1]	39.0 (28.0, 52.0)	41.0 ^{a} (31.0, 57.0)	44.0 ^{a} (32.0, 58.7)	34.0 ^{b} (25.0, 45.0)	39.0 ^{c} (27.0, 51.0)
Weight [kg] [1]	52.7 (47.9, 59.2)	53.8 ^{a} (47.9, 62.3)	55.0 ^{a} (49.3, 61.2)	50.5 ^{b} (46.0, 56.5)	53.0 ^{c} (49.9, 59.0)
Height [cm] [1]	156.1 (151.1, 162.1)	151.8 ^{a} (148.3, 155.4)	162.1 ^{b} (158.0, 166.7)	153.1 ^{c} (149.0, 156.8)	162.0 ^{b} (157.2, 166.7)
BMI [kg/m^2] [1]	21.3 (19.6, 23.7)	23.5 ^{a} (21.0, 26.4)	21.0 ^{b} (19.5, 22.7)	21.5 ^{c} (19.9, 23.7)	20.2 ^{d} (19.1, 21.7)
<18.5 kg/m^2	12.0 (183)	6.9 (25)	13.6 (42)	10.9 (53)	17.1 (63)
18.5–24.9 kg/m^2	72.0 (1098)	58.0 (210)	78.2 (241)	73.6 (359)	78.3 (288)
25–29.9 kg/m^2	12.3 (187)	23.8 (86)	7.1 (22)	13.5 (66)	3.5 (13)
≥30 kg/m^2	3.8 (58)	11.3 (41) ^{a}	1.0 (3) ^{b}	2.0 (10) ^{c}	1.1 (4) ^{b}
≥25 kg/m^2	16.0 (245)	35.1 (127) ^{a}	8.1 (25) ^{b}	15.6 (76) ^{c}	4.6 (17) ^{d}
MUAC [cm] [1]	27.1 (25.4, 29.1)	28.1 ^{a} (26.1, 31.5)	26.8 ^{b} (24.7, 28.5)	27.3 ^{c} (25.6, 29.5)	26.4 ^{b} (24.9, 28.0)
MUAC < 24 cm, % (n) [2]	10.1 (154)	7.2 (26) ^{a}	14.9 (46) ^{b}	6.4 (31) ^{a}	13.8 (51) ^{b}
MUAC ≥ 30 cm, % (n) [2]	14.6 (223)	22.4 (81) ^{a}	8.8 (27) ^{b}	18.0 (88) ^{c}	7.3 (27) ^{b}
MUAC ≥ 33.5 cm, % (n) [2]	4.5 (69)	11.0 (40) ^{a}	1.3 (4) ^{b}	4.3 (21) ^{c}	1.1 (4) ^{b}
Hemoglobin, g/L [1]	129 (117, 140)	127 ^{a} (117, 136)	140 ^{b} (129, 152)	120 ^{c} (109, 129)	138 ^{d} (126, 148)
Anemia, % (n) [2]	34.6 (528)	29.0 (105) ^{a}	25.0 (77) ^{b}	48.0 (234) ^{c}	30.4 (112) ^{a}
Pregnant, % (n) [2]	3.6 (55)	3.0 (11)	-	9.0 (44)	-
Diarrhea, 4 weeks, % (n) [2]	2.4 (37)	4.1 (15) ^{a}	1.6 (5) ^{b}	2.9 (14) ^{c}	0.8 (3) ^{b}
Malaria, 90 days, % (n) [2]	33.8 (516)	17.7 (64) ^{a}	16.3 (50) ^{a}	53.5 (261) ^{b}	38.2 (141) ^{c}

TZ = Tanzania, MZ = Mozambique; TZ-F = TZ-female, TZ-M = TZ-male, MZ-F = MZ-female, MZ-M = MZ-male, BMI = body mass Index, and MUAC = mid-upper arm circumference. Data are the median (interquartile range) [1] and percentage (number) [2]. Differences between individual groups were assessed by the Kruskal–Wallis and pairwise multiple comparison tests or the Chi Square test as appropriate (all p values are <0.001 for general group comparisons); values within a row not sharing a common superscript letter (^{a,b,c,d}) are significantly different at $p < 0.05$. MUAC cut-off <24 cm for underweight [28], ≥30 cm for overweight and ≥33.5 cm for obesity [27]. Anemia is defined as hemoglobin <120 g/L for non-pregnant and <110 g/L for pregnant women and <130 g/L for men [29].

Table 2. Macro- and micronutrient intake of the farmers in comparison to recommended daily intake (RDI).

	All (N = 1526)	**TZ-F (N = 362)**	**TZ-M (N = 307)**	**MZ-F (N = 488)**	**MZ-M (N = 369)**	**RDI/d**
Energy [kcal] [1]	2261 (1564, 2974)	2071 ^{a} (1589, 2778)	2615 ^{b} (2025, 3286)	2178 ^{a} (1373, 2912)	2211 ^{a} (1369, 3037)	1900–2800
E ≥ RDI [2], % (n)	46.5 (710)	51.1 (185) ^{a}	48.2 (148) ^{a}	51.0 (249) ^{a}	34.7 (128) ^{b}	
Protein [g]	60.3 (39.5, 88.9)	69.6 ^{a} (48.1, 98.8)	86.3 ^{b} (62.4, 112.5)	49.1 ^{c} (33.1, 68.7)	49.8 ^{c} (30.3, 76.2)	47–68
Pro ≥ RDI, % (n)	60.0 (915)	74.0 (268) ^{a}	79.2 (243) ^{a}	51.2 (250) ^{b}	41.7 (154) ^{c}	
Fat [g]	44.6 (30.7, 66.2)	42.0 ^{a} (26.4, 62.9)	51.0 ^{b} (35.1, 74.7)	43.5 ^{a} (32.5, 62.8)	44.7 ^{a} (28.2, 63.9)	

Table 2. *Cont.*

	All (N = 1526)	TZ-F (N = 362)	TZ-M (N = 307)	MZ-F (N = 488)	MZ-M (N = 369)	RDI/d
CHO [g]	398.3 (263.3, 528.8)	371.7 [a] (266.1, 479.8)	451.2 [b] (346.7, 553.3)	390.4 [a] (227.2, 523.9)	399.5 [a] (220.6, 543.6)	
Retinol equiv. [μg]	50.8 (24.6, 207.6)	94.4 [a] (24.0, 265.0)	121.5 [a] (29.0, 311.0)	44.2 [b] (24.6, 143.2)	44.2 [b] (23.9, 127.2)	500–800
RE ≥ RDI, % (n)	9.9 (151)	13.0 (47) [a]	13.7 (42) [a]	8.8 (43) [b]	5.1 (19) [c]	
Vitamin E [mg]	2.5 (1.2, 4.9)	1.8 [a] (1.5, 3.0)	3.0 [b] (1.5, 3.3)	2.5 [b] (0.9, 5.0)	2.5 [a,b] (0.0, 5.0)	7.5–10
VE ≥ RDI, % (n)	6.6 (101)	6.4 (23) [a]	5.5 (17) [a]	8.2 (40) [a]	5.7 (21) [a]	
Vitamin B1 [mg]	1.7 (1.1, 2.5)	1.5 [a] (1.0, 2.2)	1.9 [b] (1.4, 2.4)	1.8 [b] (1.1, 2.6)	1.7 [b] (1.0, 2.6)	1.1–1.4
B1 ≥ RDI, % (n)	73.6 (1123)	70.7 (256) [a,c]	83.7 (257) [b]	74.4 (363) [a]	66.9 (247) [c]	
Vitamin B2 [mg]	1.1 (0.7, 1.6)	1.3 [a] (0.8, 2.0)	1.6 [b] (1.1, 2.1)	0.9 [c] (0.5, 1.3)	0.9 [c] (0.5, 1.3)	1.0–1.4
B2 ≥ RDI, % (n)	46.0 (702)	61.6 (223) [a]	64.5 (198) [a]	39.1 (191) [b]	24.4 (90) [c]	
Vitamin B6 [mg]	1.9 (1.2, 2.8)	1.6 [a] (1.0, 2.3)	2.0 [b] (1.5, 2.7)	1.9 [b] (1.1, 3.0)	2.0 [b] (1.1, 3.4)	1.2–1.9
B6 ≥ RDI, % (n)	67.6 (1031)	60.8 (220) [a]	77.2 (237) [b]	68.4 (334) [b,c]	65.0 (240) [a,c]	
Folic acid [μg]	431.5 (216.5, 780.0)	611.7 [a] (334.5, 1011.1)	748.8 [b] (406.9, 1058.0)	320.0 [c] (177.5, 522.6)	318.7 [c] (161.1, 544.4)	400–600
FA ≥ RDI, % (n)	52.6 (803)	70.4 (255) [a]	75.9 (233) [a]	35.7 (174) [b]	38.2 (141) [b]	
Vitamin B12 [μg]	0 (0, 0.6)	0 [a] (0, 0.4)	0 [a] (0, 0.6)	0 [a] (0, 0.6)	0 [a] (0, 0.8)	2.4–2.6
B12 ≥ RDI, % (n)	11.8 (180)	15.2 (55) [a]	17.9 (55) [a]	7.2 (35) [b]	9.5 (35) [b]	
Vitamin C [mg]	56.5 (23.4, 1178)	36.8 [a] (9.8, 76.3)	39.1 [a] (14.0, 92.5)	77.4 [b] (32.9, 144.1)	68.5 [b] (32.1, 131.5)	40–55
VC ≥ RDI, % (n)	56.4 (860)	43.4 (157) [a]	46.9 (144) [a]	66.2 (323) [b]	64.0 (236) [b]	
Calcium [mg]	334.5 (196.0, 574.8)	357.0 [a] (200.8, 652.0)	403.3 [b] (253.0, 600.0)	280.5 [c] (176.6, 510.1)	312.0 [c] (176.9, 599.3)	1000–1300
Ca ≥ RDI, % (n)	11.2 (171)	14.6 (53) [a]	16.0 (49) [a]	6.8 (33) [b]	9.8 (36) [b]	
Magnesium [mg]	485.0 (297.4, 763.0)	420.8 [a] (259.6, 619.1)	465.2 [b] (300.0, 673.8)	552.4 [c] (333.5, 810.6)	553.1 [a,c] (293.4, 819.2)	190–260
Mg ≥ RDI, % (n)	82.6 (1261)	82.0 (297) [a,b]	82.7 (254) [a,b]	86.5 (422) [a]	78.0 (288) [b]	
Iron [mg]	20.3 (12.8, 27.9)	18.0 [a] (11.5, 23,5)	21.5 [b] (15.6, 27.6)	20.8 [b] (12.7, 29.3)	22.1 [b] (12.6, 32.7)	11–31
Fe ≥ RDI, % (n)	51.4 (784)	33.7 (122) [a]	79.5 (244) [b]	32.4 (158) [a]	70.5 (260) [c]	
Zinc [mg]	11.1 (7.0, 15.2)	11.4 [a] (7.2, 15.6)	13.0 [b] (9.5, 17.6)	10.1 [c] (6.4, 14.0)	10.5 [c] (6.1, 14.5)	9.8–19.2
Zn ≥ RDI, % (n)	44.4 (678)	56.1 (203) [a]	43.0 (132) [b]	49.6 (242) [a,b]	27.4 (101) [c]	

Data are the median (interquartile range (IQR)) [1] and percentage (number) [2]. RE, retinol equivalent; RDI/day: recommended daily nutrient intake of macro- and micronutrients adjusted for age (19–50, 51–65 years), sex and pregnancy status following the FAO/WHO [35] and D-A-C-H [34] recommendations; the low bioavailability for zinc and the 10% bioavailability for iron were applied [35]. Groups were compared using the Kruskal–Wallis and pairwise comparison tests and the Chi Square test as appropriate; all p values are <0.001, except for EE ≥ RDI = 0.042, zinc ≥ RDI = 0.008 and Mg ≥ RDI = 0.002; villages not sharing a superscript letter ([a,b,c]) are significantly different ($p < 0.05$). RDI: energy [kcal]: female: 2300 to18 years, 2200 to 25 years, 2100 to 51 years, 2000 to 65 years, 1900 in 65 + years; trim2: +250, trim3: +500; male: 2800 to 25 years, 2700 to 51 years, 2500 to 65 years, 2500 to 65+ years; protein [g]: female: 48 to18 years; 47 to 65 years; 57 to 65+ years; pregnant: trim2: +7; trim3: +21; male: 62 to18 years, 57 to 51 years; 55 to 65 years; 67 to 65+ years; retinol equivalent s [μg]: female 19–65 years: 500; male and female 65+ years: 600; pregnant: 800; vitamin E [mg]: female: 7.5; male: 10; vitamin B1 [mg]: female: 1.1 all; pregnant: 1.4; male: 1.2 all; vitamin B2 [mg]: female: adolescents 1.0 and adults 1.1; pregnant: 1.4; male: 1.3 all; vitamin B6 [mg]: female: adolescents 1.2 and 19–50 years 1.3 and 51–65+ 1.5; pregnant: 1.9; male: adolescents–50 y: 1.3 and 51–65+ years: 1.7; FA [μg]: 400 for all; pregnant: 600; vitamin B12 [μg]: 2.4 for all; pregnant: 2.6; vitamin C [mg]: adolescents 40 and adults 45; pregnant: 55; calcium [mg]: male (19–65 years) and female (19–51 years): 1000; female adolescents, female 51+ years and male 65+ years: 1300; pregnant: 1200; magnesium [mg]: female adolescents 230; female 19–65 years and pregnant: 220; female 65+ years: 190; male: adolescents 250, male 19–65 years: 260; male 65+ years: 230; iron [mg]: female adolescents 31; female 19–51 years: 29; female 51+ years: 11; male adolescents: 19; male 19–65+ years: 14; zinc [mg]: pregnant: 14, female adolescents: 15.5, female 19–65+ years: 9.8; male: adolescents: 19.2; male 19−65+ years: 14.

The farmers from Tanzania were better supplied than the farmers from Mozambique with regard to vitamin B2, folic acid and vitamin B12, whereas there was barely any difference between the countries for vitamin B1 and B6, with the lowest intake in women from Tanzania. In contrast, the intake of vitamin C was double as high in farmers from Mozambique than farmers from Tanzania. Farmers from Tanzania showed a significantly higher intake of calcium in comparison to farmers from Mozambique; however, only a small proportion of Mozambican (7–10%) and Tanzanian farmers (15–16%) reached the recommended daily intake of calcium. In contrast, farmers in both countries showed an adequate intake of magnesium, with approximately 80% of the RDI. Women had a similar intake of iron as men, whereas only one in three women reached the gender-specific RDI for iron, compared to two in three men. The zinc intakes were lower in Mozambique than in Tanzania, with the lowest intake among Mozambican men.

Table 3 summarizes the frequency and the median quantity of consumed foods according to the 14 food groups, as reported in the 24 h recalls. The portions consumed were determined using a booklet with pictures of different defined (e.g., 125 g, 250 g or 500 g) portion sizes of food weighed in advance to allow a more accurate assessment by the farmers. In Tanzania, almost all female and male participants (98%) reported the consumption of 'cereals', while in Mozambique 82% of female and 76% of male farmers had cereals the previous day. In terms of quantity, men from Tanzania have recorded the highest consumption of cereals. Legumes were the second most consumed food group in both countries, with both frequency and quantity consumed significantly higher in Tanzania than in Mozambique. 'Starchy plants' were more frequently and in larger quantities consumed in Mozambique compared to Tanzania. Further, female and male farmers from Mozambique consumed 'fish', 'meat', 'other vegetables', 'sugar and sweets' more often, but the Tanzanian farmers consumed these foods in greater quantities. Significantly more farmers from Tanzania than from Mozambique reported the consumption of energy-dense carbohydrates from 'bread and similar products', 'fruits' and 'beverages', which include tea, coffee and alcohol, whereas the consumption of 'green leafy vegetables' in Mozambique was significantly higher than in Tanzania.

Table 3. Frequency and amount of consumed food groups (in grams) by sex and country.

Food Intake	All (N = 1526)	TZ-F (N = 362)	TZ-M (N = 307)	MZ-F (N = 488)	MZ-M (N = 369)	*p*
Cereals, % (n) [1]	87.6 (1337)	97.8 (354) [a]	98.4 (302) [a]	81.8 (399) [b]	76.4 (282) [c]	<0.001
Grams [2]	625 (500, 1000)	500 (500, 1000) [a]	1000 (500, 1000) [b]	500 (380, 1000) [c]	500 (500, 1000) [d]	<0.001
Bread and prod., % (n)	15.3 (233)	25.1 (91) [a]	28.0 (86) [a]	5.1 (25) [b]	8.4 (31) [b]	<0.001
Grams	160 (100, 160)	160 (120, 160) [a]	160 (160, 240) [a]	100 (60, 130) [b]	65 (60, 110) [b]	<0.001
Starchy plants, % (n)	41.7 (637)	35.9 (130) [a]	39.1 (120) [a,b]	46.1 (225) [b]	43.9 (162) [a,b]	0.015
Grams	360 (240, 500)	300 (200, 400) [a]	300 (200, 400) [a,b]	400 (250, 600) [b]	450 (250, 750) [b]	<0.001
Legumes, % (n)	63.2 (965)	73.2 (265) [a]	75.6 (232) [a]	55.7 (272) [b]	53.1 (196) [b]	<0.001
Grams	250 (195, 500)	500 (250, 500) [a]	500 (250, 500) [a]	249 (125, 280) [b]	250 (125, 280) [b]	<0.001
DGLVs, % (n)	31.3 (477)	19.9 (72) [a]	18.2 (56) [a]	42.4 (207) [b]	38.5 (142) [b]	<0.001
Grams	250 (125, 250)	250 (125, 394) [a]	250 (150, 500) [a]	250 (125, 250) [b]	185 (125, 250) [b]	<0.001
Other vegetables, % (n)	21.5 (328)	8.6 (31) [a]	8.8 (27) [a]	33.4 (163) [b]	29.0 (107) [b]	<0.001
Grams	187.5 (125, 250)	200 (125, 250) [a]	250 (150, 500) [a]	145 (120, 250) [b]	162 (120, 250) [b]	0.282
Fruits, % (n)	9.8 (149)	19.3 (70) [a]	17.6 (54) [a]	2.0 (10) [b]	4.1 (15) [b]	<0.001
Grams	200 (120, 300)	180 (120, 255) [a]	240 (120, 300) [a]	200 (142, 275) [b]	300 (200, 400) [b]	<0.001
Nuts, % (n)	2.8 (42)	3.0 (11) [a,b]	5.9 (18) [a]	1.2 (6) [b]	1.9 (7) [b]	0.001
Grams	90 (50, 100)	100 (50, 100) [a,b]	100 (50, 100) [a]	40 (19, 100) [b]	50 (25, 50) [b]	0.081
Fish, % (n)	23.7 (362)	18.8 (68) [a]	22.8 (70) [a,b]	24.8 (121) [b]	27.9 (103) [b]	0.030
Grams	125 (90, 250)	250 (125, 250) [a]	250 (150, 300) [a]	100 (60, 170) [b]	100 (70, 180) [b]	<0.001
Meat, % (n)	12.3 (187)	7.4 (27) [a]	11.1 (34) [a,b]	12.5 (61) [b, c]	17.6 (65) [c]	<0.001
Grams	150 (100, 240)	200 (125, 300) [a]	250 (150, 400) [a,b]	120 (90, 180) [a,b]	120 (90, 180) [b]	<0.001

Table 3. *Cont.*

Food Intake	All (N = 1526)	TZ-F (N = 362)	TZ-M (N = 307)	MZ-F (N = 488)	MZ-M (N = 369)	*p*
Eggs and diary, % (n)	2.6 (39)	4.1 (15) [a]	4.2 (13) [a]	1.4 (7) [b]	1.1 (4) [b]	0.005
Grams	120 (80, 180)	120 (80, 250) [a]	140 (65, 340) [a,b]	110 (80, 150) [a,b]	70 (45, 80) [b]	0.102
Sugar and sweets, % (n)	4.5 (69)	1.9 (7) [a]	2.6 (8) [a,b]	6.8 (33) [b]	5.7 (21) [b]	0.002
Grams	240 (87, 245)	300 (250, 400) [a]	315 (100, 500) [a]	240 (50, 240) [b]	200 (75, 240) [a,b]	0.001
Beverages, % (n)	29.8 (455)	56.9 (206) [a]	62.9 (193) [a]	5.9 (29) [b]	7.3 (27) [b]	<0.001
Grams	250 (250, 250)	250 (250, 250) [a]	250 (250, 250) [a]	250 (245, 250) [b]	250 (240, 250) [b]	<0.001

Figures are the percentages (numbers) [1] and the median (25th and 75th percentiles) [2]. *p* values: the Kruskal–Wallis test and following multiple comparison tests: values within a row not sharing a common superscript letter ([a,b,c]) are significantly different at $p < 0.05$. 'Cereals': maize, rice, sorghum, millet ('ugali', 'uji'); 'Bread and similar products': dough made from wheat or rice fried or baked in oil (bread, chapatti, noodles, African donuts, 'bhajia' (chickpea cake), and half-cake); 'Starchy plants': white potatoes, sweet and Irish potatoes, cassava, plantain, yam, and taro; 'Legumes': pigeon peas, cowpeas, kidney beans, lentils, chickpeas, and bambara nuts; 'DGLVs': cowpea leaves, spinach, amaranth leaves, cassava leaves, sweet potato leaves, mlenda (jute mallow), lettuce, and pumpkin leaves; 'Other vegetables': tomatoes, eggplant, carrots, onions, okra, cabbage, pumpkin, and mushroom; 'Fruits': mango, papaya, banana, jackfruit, avocado, orange, lemon, and mandarin; 'Nuts': groundnuts, cashews, coconut, and sesame; 'Fish': fresh or dried fish, sardines, fried fish, tuna, and shrimp; 'Meat': beef, chicken, duck, rat, goat, and pork; ' Eggs and diary': egg pancakes, eggs, milk, and yoghurt; 'Sugar and sweets': sugar, sugarcane, carbonated drinks, cola, and sweetened juices; 'Beverages': tea and beer.

The food groups consumed (in grams) as predictors and their quantitative contribution to the intake of vitamin A, iron and zinc intake are presented in Table 4. For vitamin A, DGLVs was the most significant predictor of vitamin A intake in both countries (partial R), while legumes in Tanzania and starchy plants in Mozambique were quantitatively responsible for 50% and 42% of vitamin A intake, respectively.

Legumes and cereals, in Tanzania, and cereals, in Mozambique, were the main predictors of iron intake; and legumes, cereals and fish, in Tanzania, while again cereals, in Mozambique, were the most relevant predictors of zinc intake. In Tanzania, cereals followed by legumes were also the most important food groups for iron and zinc intake in terms of quantity, while in Mozambique cereals followed by starchy plants and legumes were the quantitatively predominant food groups for both iron and zinc intake.

Table 4. Multiple linear regression assessing food groups consumption (in grams) as predictors of vitamin A (RE), iron and zinc intake.

Tanzania (N = 669)						**Mozambique (N = 857)**					
(LN) RE Intake [µg]	**B**	**Beta**	**R^2 Ch.**	**Partial R**	**%RE**	**(LN) RE Intake [µg]**	**B**	**Beta**	**R^2 Ch.**	**Partial R**	**%RE**
(Constant)	3.529366					(Constant)	3.037323				
DGLVs (g)	0.005963	0.620 **	0.328	0.625	9.1	DGLVs (g)	0.006786	0.677 **	0.363	0.654	17.0
Eggs and diary (g)	0.007574	0.220 **	0.042	0.283	1.1	Other vegetables (g)	0.002481	0.229 **	0.034	0.279	12.4
Other vegetables (g)	0.003691	0.202 **	0.033	0.259	3.4	Legumes (g)	0.001355	0.163 **	0.022	0.209	25.8
Fruits (g)	0.001419	0.102 *	0.009	0.135	6.4	Sugar and sweets (g)	0.002870	0.106 **	0.012	0.141	2.1
Starchy plants (g)	0.000854	0.103 **	0.010	0.136	18.5	Starchy plants (g)	0.000371	0.089 *	0.008	0.116	42.4
Meat (g)	0.002283	0.120 **	0.007	0.154	3.4	Eggs and diary (g)	0.008217	0.083 *	0.007	0.111	0.3
Fish (g)	0.001728	0.130 **	0.008	0.160	7.7						
Legumes (g)	0.000669	0.126 **	0.013	0.149	50.4						
(LN) **Iron Intake [mg]**	B	Beta	R^2 Ch.	Partial R	%FE	(LN) **Iron Intake [mg]**	B	Beta	R^2 Ch.	Partial R	%FE
(Constant)	1.816587					(Constant)	2.025				
Legumes (g)	0.001231	0.561 **	0.253	0.582	24.1	Cereals (g)	0.000807	0.507 **	0.255	0.547	53.5
Cereals (g)	0.000571	0.382 **	0.172	0.471	57.1	Starchy plants (g)	0.000636	0.245 **	0.053	0.300	20.5
DGLVs (g)	0.000933	0.233 **	0.040	0.308	4.4	Legumes (g)	0.001348	0.261 **	0.043	0.315	12.5
Starchy plants (g)	0.000516	0.150 **	0.023	0.211	8.8	Meat (g)	0.002639	0.194 **	0.027	0.239	2.0
Nuts (g)	0.003972	0.117 **	0.012	0.168	0.3	Fish (g)	0.001399	0.170 **	0.024	0.214	3.3
Fish (g)	0.000786	0.142 **	0.012	0.186	3.7	DGLVs (g)	0.000710	0.114 **	0.012	0.143	8.2
Meat (g)	0.001035	0.130 **	0.016	0.179	1.6						
(SR) **Zinc Intake [mg]**	B	Beta	R^2 Ch.	Partial R	%ZN	(SR) **Zinc Intake [mg]**	B	Beta	R^2 Ch.	Partial R	%ZN
(Constant)	1.731673					(Constant)	1.864001				
Legumes (g)	0.002217	0.697 **	0.318	0.751	23.2	Cereals (g)	0.001352	0.703 **	0.502	0.781	58.2
Cereals (g)	0.000762	0.353 **	0.188	0.532	54.9	Legumes (g)	0.001844	0.295 **	0.058	0.464	13.6
Fish (g)	0.003292	0.410 **	0.109	0.571	3.5	Starchy plants (g)	0.000803	0.256 **	0.052	0.415	22.3
Meat (g)	0.002692	0.234 **	0.047	0.385	1.6	Meat (g)	0.004180	0.254 **	0.059	0.412	2.2
Starchy plants (g)	0.000638	0.128 **	0.013	0.225	8.5	Fish (g)	0.001227	0.124 **	0.016	0.216	3.6
DGLVs (g)	0.000691	0.119 **	0.012	0.207	4.2	Nuts (g)	0.011565	0.078 **	0.006	0.139	0.1
Nuts (g)	0.005260	0.107 **	0.012	0.195	0.3						
Eggs and milk (g)	0.001752	0.084 **	0.008	0.153	0.5						
Bread (g)	0.000688	0.064 **	0.004	0.114	3.3						

LN = log-normal; SR = square root; B = beta coefficient; Beta = standardized beta coefficient; RE = retinol equivalents; FE = iron; ZN = zinc; * $p < 0.05$, ** $p < 0.001$ (probability of F: entry 0.01, removal 0.05), and % percentage; micronutrient contribution of consumed food group calculated by frequency and mean consumption.

4. Discussion

The present study confirms the trend of an increasing prevalence of overweight and obesity, joint with a simultaneously high prevalence of anemia and deficient micronutrient intake in East-African female and male farmers [36,37].

Significant differences between farmers from Lindi, Tanzania and Gurué, Mozambique in terms of frequently and quantitatively consumed food items, micronutrient intake and respective nutritional status were evident. Women of both countries had a significantly higher prevalence of overweight and obesity compared to men, but at the same time a lower dietary intake of iron, significantly lower hemoglobin concentrations and accordingly a higher prevalence of anemia. Hence, it was observed that men were only half as often affected by anemia compared to women from both countries who were twice as likely to have reached the recommended daily intake (RDI) for iron intake. Low iron intake in combination with low or limited iron bioavailability, caused by a high concentration of the anti-nutrients phytate and tannin present in, e.g., black tea and plant-based diets and particularly in beans, could be one explanation for the higher prevalence of anemia in female farmers of our study [38,39]. The insufficient dietary intake of vitamin A and pro-vitamin A active carotenoid in female and male farmers of the present study, where 9 in 10 farmers did not reach the daily intake recommendations may have further reduced the iron bioavailability. Vegetables rich in β-carotene are able to significantly improve the bioavailability of iron from cereals and pulses as verified in a study on corn, wheat and rice, explaining that β-carotene forms a complex with iron, keeping it soluble in the intestinal lumen and preventing the inhibitory effect of phytate on iron absorption [40]. Ascorbic acid from fruits, which were rarely consumed in both countries can similarly enhance the absorption of iron from vegetarian diets [41]. Previous studies reported that traditional food preparation and cooking methods (fermentation, boiling, or frying) with reduced cooking time can significantly reduce phytate content in vegetables [42,43]. Various analysis of DGLVs confirmed them as excellent sources of β-carotene, iron and other minerals [44,45]. Nevertheless, according to the dietary assessment of the farmers of this study only every fifth person in Tanzania and every second person in Mozambique reported consuming DGLVs. A study among 90 pregnant women from Tanzania showed significant improvements of vitamin A status (plasma retinol) through an increased consumption of green leafy vegetables with oil, which increases the bioavailability of pro-vitamin A carotenoid [46]. Another study on 666 mother–children pairs from two different districts of rural Tanzania proved that the consumption of whole-grain millet with DGLVs led to improved blood iron status (mothers and children) and better vitamin A status (retinol in serum of mothers) compared to processed grains with legumes, which consequently resulted in a significantly lower prevalence of anemia and iron deficiency [21,47]. In the present study, the prevalence of anemia and the deficient dietary intake of vitamin A and iron was the highest in female farmers from Mozambique. Every second woman (48%) was anemic and every second woman (53%) also reported having malaria in the last three months. The identified effect of malaria infections on erythropoiesis and the iron recycling that occurs after parasite-induced hemolysis may be responsible for the high anemia rates [48], as previously shown in African refugees [49]. According to the 24 h recalls of the female and male farmers of both countries, their main meal consisted of cereals in form of polished rice or maize combined with a serving of legumes. Large amounts of refined carbohydrates and too few micronutrient-rich vegetables (DGLVs) and food of animal origin are most likely the cause for the existing multiple burden of overweight/obesity, anemia, and insufficient dietary intake of vitamin A, iron and zinc, as also shown in previous studies [50]. These inadequate and insufficiently diversified eating habits have been already reported in Tanzanian farmers from Morogoro, with diets consisting of less than six food groups of a total of 12 defined possible food groups, and unmet dietary micronutrient intake recommendations [51]. A high intake of refined grains was recently associated with a higher risk of obesity, major cardiovascular disease events and mortality [52]. The general nutrition transition characterized by the paradoxical coexistence of micronutrient deficiencies, underweight and pre-obesity/obesity has been already noted frequently in urban and rural Africa, as obesity becomes a condition more associated with poverty due to the increasing affordability of highly refined oils, sugar-sweetened beverages and carbohydrates [53,54]. In the present study, the significantly more frequent consumption of sugar-sweetened beverages in Tanzania compared to Mozambique (57–63% vs. 6–7%) is very likely one of the causes for the higher prevalence of overweight there. A review from 2014 also demonstrated how the increase in sugar intake, with an intake higher than the recommended 40 g per day, was a powerful predictor of overweight and obesity in countries of Sub-Saharan Africa, including Tanzania [55,56]. A recent study, conducting data between 2008 and 2017, from 23 countries of Sub-Saharan Africa including Tanzania and Mozambique found out that a triple burden of malnutrition (anemia, underweight and overweight) was present in 5–8% of the households and that interventions must address overweight/obesity but also undernutrition and anemia [57]. A study on 976 adolescents from Ghana stated an even higher prevalence of overweight than in the present study with almost half of female and male adolescents (48%) overweight, while approximately one-third of males (30.5%) and half of females (52.2%) had mild (females:110–119 g/L, males: 110–129 g/L) to severe (<80 g/L) anemia [58,59]. According to the WHO classification of public health significance, the prevalence of anemia was $\geq$40%, as detected in the female farmers in Mozambique of the present study, and the female adolescents of the study from Ghana is considered a severe global public health problem [59]. A similarly high prevalence of overweight (53%) and anemia (38%) was reported in a national study among non-pregnant women (n = 3089, 15–49 years) from Azerbaijan, where the rates of vitamin A deficiency (11%), iron deficiency (34%) and iron-deficiency anemia (24%) were substantially high [60].

In addition to the power of the present study, there were limitations such as the cross-sectional design and thus single time point of hemoglobin measurement and dietary intake. Further, common under-reporting of portion sizes and of consumed sugar in teas or porridges in the 24 h recalls might have biased the food intake in terms of energy of the farmers in this study. Another limitation is that we measured deficiencies of micronutrients through dietary intake only; further, hemoglobin was measured, but unfortunately, we did not take blood samples for the measurement of biological markers; here, blood parameters such as ferritin and haptoglobin would have been beneficial to determine the status of iron deficiency in relation to measured anemia rates. The strengths of this study include the large sample size and the assessment of both female and male farmers from two different villages in each of the regions studied, Lindi in Southern Tanzania and Zambézia in North-western Mozambique. All enrolled farmers were measured (anthropometry and hemoglobin) and interviewed by two well-trained teams within 6 weeks.

5. Conclusions

In conclusion, the outcomes of the present study suggest a strong impact of dietary habits on the prevalence of overweight and micronutrient deficiencies among Tanzanian and Mozambican female and male small-scale pigeon pea farmers.

In terms of overweight, anemia and deficiencies of vitamin A and iron, a micronutrient-rich diet with whole grains, more legumes and especially DGLVs would be advantageous over a diet consisting mainly of polished maize or rice and insufficient amounts of vegetables, legumes and fruits. Further, interventions within the Vegi-Leg project, including nutritional educational programs and the development and introduction of proper drying techniques for leafy vegetables and pigeon peas that conserve micronutrients, are promising measures to reduce the high prevalence of anemia, micronutrient deficiencies and overweight among small-scale farmers of the study areas.

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3.2 Impact of study region and seasonality on diet and hemoglobin status (Follow up study)

Seasonal variations from dry to rainy season can cause relevant effects on dietary habits of farmers and further on their nutritional status, as well as the prevalence of anemia and micronutrient deficiencies. In the present study, results of the Household Dietary Diversity Score (HDDS) showed a higher mean HDDS in Gurué region, Mozambique compared to Lindi region, Tanzania (8.74 vs. 8.29) [Table 3.1]. In Gurué, the consumption of 'green leafy vegetables' (48.7% vs. 65.7%), 'nuts and seeds' (30.6% vs. 42.8%), 'fish and seafood' (37.8% vs. 56.6%), 'meat' (25.1% vs. 42.0%), and 'eggs, milk and milk products' (20.3% vs. 35.0%) was significantly higher than in Lindi, whereas in Lindi, the consumption of 'oil and fat' (91.8% vs. 85.0%), and 'tea, coffee and alcoholic beverages' (73.0% vs. 41.9%) was significantly higher than in Gurué, showing a higher food diversity in Gurué compared to Lindi. The results showed a higher consumption frequency of animal-based food groups like 'fish and seafood', 'meat' and 'eggs, milk and milk products' in Gurué than in Lindi. The reported food groups 'cereals', 'fruits' and 'sugar and sweets' did not exhibit significant differences between Gurué and Lindi. 'Cereals' were consumed in nearly all households of both study regions.

Table 3.1 HDDS at Vegi-Leg baseline study

	Lindi, TZ	Gurué, MZ
N	669	855
HDDS, mean ± SD[1]	8.29 ± 2.98*	8.74 ± 3.43
HDDS, Median (IQR)[2]	8 (6, 10)*	8 (6, 12)
Cereals[3], %(n)	97.6 (654)*	96.5 (825)
Bread & similar products, %(n)	43.0 (288)*	51.2 (438)
Starchy plants, %(n)	61.2 (410)**	70.9 (606)
Legumes/ Pulses, %(n)	83.1 (557)*	78.6 (672)
Green leafy vegetables, %(n)	48.7 (326)**	65.7 (562)
Other vegetables, %(n)	91.0 (610)*	89.4 (764)
Fruits, %(n)	55.8 (374)	50.6 (433)
Nuts & Seeds, %(n)	30.6 (205)**	42.8 (366)
Oil & Fat, %(n)	91.8 (615)**	85.0 (727)
Fish & Seafood, %(n)	37.8 (253)**	56.6 (484)

Flesh meat & organs, %(n)	25.1 (168)**	42.0 (359)
Eggs, Milk- & products, %(n)	20.3 (136)**	35.0 (299)
Sugar & Sweets, %(n)	69.7 (467)**	68.2 (583)
Tea, Coffee & Alcohol, %(n)	73.0 (489)**	41.9 (358)

Mean HDDS = sum (HDDS) / total number of households; data are percentage (number), %(n), *p<0.05 and ** p< 0.001

Mean and median HDDS decreased significantly during the follow-up surveys in the rainy season of both study regions. The mean HDDS decreased by 1.22 and 1.16 in the follow up studies in Lindi (April) and Gurué (December) respectively, in comparison to the baseline studies (in July-August) [Table 3.2]. The farmers from Lindi (97.8% and 98.1%) and from Gurué (96.1% and 92.2%) reported the highest consumption frequency for the food group 'cereals', consistent for both seasons. Among farmers in Lindi, 9 of 14 food groups were consumed less frequently in the rainy season compared to the dry season. A major decline was evident in the consumption of 'legumes and pulses' (from 83.1% to 33.8%), 'fruits' (from 55.9%, to 30.3%) and 'sugar and sweets' (from 42.3% to 25.8%). 'Cereals', 'other vegetables', 'nuts and seeds' and 'fish and seafood' were equally often consumed in the Lindi households during both seasons, while 'green leafy vegetables' as the only food group were more frequently consumed in the rainy season compared to the dry season, (71.9% vs. 49.0%).

In Gurué, the farmers consumed 12 of the 14 food groups less frequently during the rainy season in December 2019 compared to the dry season in April 2019. The largest decreases (all p<0.001) in consumption of specific food groups were as follows: : 'sugar and sweets' (from 66.0% to 34.7%;), 'tea, coffee and alcoholic beverages' (from 42.1% to 22.8%;), as well as 'flesh meat and organ meat' (from 42.3% to 25.8%;). Only two of the 14 food groups were significantly more often consumed in the follow-up survey; 'fruits' (90.2%; vs. 49.5% p<0.001) and 'green leafy vegetables' (85.7% vs. 67.3%

Table 3.2 Comparison of HDDS between dry and rainy season in Lindi, Tanzania and Gurué, Mozambique

	Lindi Baseline	Lindi Follow-up	Trend	Gurué Baseline	Gurué Follow-up	Trend
N	**580**	**580**	**-**	**539**	**539**	**-**
HDDS, mean ± SD[1]	**8.29** ± 2.95	**7.07** ± 2.48	- 1.22**	**8.64** ± 3.47	**7.48** ± 3.31	- 1.16**
HDDS, Median (IQR)[2]	**8** (6, 10)	**7** (5, 8)	- 1**	**8** (6, 11)	**7** (5, 9)	- 1.0**
Cereals[3]	97.8 (567)	98.1 (569)	+ 0.3 %	96.1 (518)	92.2 (597)	- 3.9 %*
Bread & similar products	43.3 (251)	32.8 (190)	- 10.5 %**	51.2 (276)	42.5 (229)	- 8.7 %*
Starchy plants	61.4 (356)	53.3 (309)	- 8.1 %*	69.2 (373)	53.1 (286)	- 16.1 %**
Legumes/Pulses	83.1 (482)	33.8 (196)**	- 49.3 %**	76.8 (414)	60.7 (327)	- 16.1 %**
Green leafy vegetables	49.0 (284)	71.9 (417)	+ 22.9 %**	67.3 (363)	85.7 (462)	+ 18.4 %**
Other vegetables	91.4 (530)	90.0 (522)	- 1.4 %	90.2 (486)	73.8 (498)	- 16.4 %**
Fruits	55.9 (324)	30.3 (176)	- 25.6 %**	49.5 (267)	90.2 (486)	+ 40.7 %**
Nuts & Seeds	31.0 (180)	27.1 (157)	- 3.9 %	40.3 (217)	34.0 (183)	- 6.3 %*
Oil & Fat	92.8 (538)	89.1 (517)	- 3.7 %*	85.0 (458)	68.6 (370)	- 16.5 %**
Fish & Seafood	37.4 (217)	35.9 (208)	- 1.5 %	54.2 (292)	44.9 (242)	- 9.3 %*
Flesh meat & organs	24.7 (143)	12.8 (74)	- 11.9 %**	42.3 (228)	25.8 (139)	-16.5 %**
Eggs, Milk- & products	19.3 (112)	7.6 (44)	- 11.4 %**	33.4 (180)	19.5 (105)	- 13.9 %**
Sugar & Sweets	69.7 (404)	57.6 (334)	- 12.1 %**	66.0 (356)	34.7 (187)	- 31.3 %**
Tea, Coffee & Alcohol	72.4 (420)	66.9 (388)	- 5.5 %*	42.1 (227)	22.8 (123)	- 19.3 %**

Data are percentage (number), %(n), *p<0.05 and ** p< 0.001

FFQ in Lindi, Tanzania during baseline and follow-up studies

The ten most commonly consumed foods at the baseline study (July) in Lindi, TZ compared to the follow-up study in the rainy season (March) are listed in Table 3.3.

Consistent for both seasons, maize was the most frequently consumed food item. On average, farmers in Lindi consumed maize 12 times and rice two times per week consistent in both seasons. While in the baseline survey the farmers reported consuming pigeon peas five times per week, the median pigeon peas consumption frequency in the follow-up survey decreased to zero ($p<0.001$). This observation was constant for both study villages in Tanzania: in Mitumbati the median pigeon peas consumption frequency decreased significantly from six to zero and in Mibure from four to zero per week. The weekly consumption of the most consumed vegetables in Lindi, tomatoes and onions, decreased significantly in March compared to the baseline survey in July (Tomatoes: 0 vs.5, Onions: 3 vs.5; $p<0.001$). Concerning the fruit consumption, oranges represented the most frequently consumed fruit in the baseline survey in Lindi, which decreased significantly in the follow-up survey in March from two to zero ($p<0.001$). Altogether, the consumption frequency of staple foods like maize or rice remained relatively constant, while legumes and pulses like pigeon peas, and vegetables like tomatoes and onions revealed high seasonal fluctuations (decreases) regarding the consumption frequency between July 2019 and March 2020. Cassava and pumpkin leaves, on the contrary, were increasingly consumed during the rainy season.

Table 3.3 FFQ of the ten most frequently consumed food items per week in Lindi, Tanzania for both survey times

Food items, FFQ	Lindi (TZ) Baseline	Lindi (TZ) Follow-up	Trend	Mitumbati Baseline	Mitumbati Follow-up	Mibure Baseline	Mibure Follow-up
N	**580**	**580**	**-**	**293**	**293**	**287**	**287**
Maize	12 (7, 14) 0 - 21	12 (7, 14) 0 - 21	0	12 (7, 14) 0 - 21	13** (8, 14) 0 - 21	12 (7, 14) 0 - 21	12 (7, 14) 0 - 16
Rice	2 (0, 2) 0 - 14	2 (0, 2) 0 – 14	0	2 (0, 3) 0 - 14	1** (0, 2) 0 - 7	1 (0, 2) 0 - 12	2** (0, 3) 0 - 12
Cassava	1*** (0, 2) 0 - 14	2 (1, 4) 0 - 14	+1	1 (0, 3) 0 - 14	3*** (2, 4) 0 - 14	0 (0, 2) 0 - 12	2*** (0, 4) 0 - 8
Pigeon peas	5*** (3, 8) 0 - 20	0 (0, 1) 0 - 9	-5	6 (3, 12) 0 - 20	0*** (0, 2) 0 - 9	4 (2, 7) 0 - 14	0*** (0, 0.1) 0 - 6
Pumpkin leaves	0*** (0, 0) 0 - 14	2 (1, 3) 0 - 14	+2	0 (0, 0) 0 - 14	2*** (1, 3) 0 - 14	0 (0, 1) 0 - 12	2*** (2, 4) 0 - 7
Tomatoes	5*** (0, 7) 0 - 18	0 (0, 2) 0 - 14	-5	3 (0, 7) 0 - 14	0*** (0, 0) 0 - 14	7 (3, 7) 0 - 18	0*** (0, 4) 0 - 14
Onions	5*** (0, 7) 0 - 18	3 (0, 7) 0 - 14	-2	3 (0, 7) 0 - 14	3 (0, 7) 0 - 14	7 (3, 7) 0 - 18	4*** (0, 7) 0 - 14
Oranges	2*** (0, 5) 0 - 25	0 (0, 0) 0 - 7	-2	2 (0, 4) 0 - 21	0*** (0, 0) 0 - 6	2 (0, 5) 0 - 25	0*** (0, 0) 0 - 7
Sugar	5** (1, 7) 0 - 14	3 (1, 7) 0 - 43	-2	5 (2, 7) 0 - 14	3*** (1, 7) 0 - 43	4 (0, 7) 0 - 14	3 (1, 6) 0 - 10
Tea	5* (1, 7) 0 - 14	4 (2, 7) 0 - 17	-1	6 (2, 7) 0 - 14	4*** (2, 7) 0 - 17	4 (0, 7) 0 - 14	4 (2, 7) 0 - 10

Figures are median (25th and 75th percentile) and minimum - maximum of food consumption per week, all such values.
Trend: median of 'Lindi Follow-Up' – median 'Lindi Baseline'.
P-Values: related-samples Wilcoxon signed ranks test. P-Values: *<0.05, **<0.01, ***<0.001.

The median consumption frequencies of the 14 different FFQ food groups during both seasons are listed in Table 3.4. Cereals were consumed two times daily during both seasons, whereas starchy plants were consumed more frequently during the rainy season (4,5 vs. 2). The weekly consumption frequency of 'legumes and pulses' decreased significantly in the rainy season (from 7 to 2; p<0.001), while the consumption frequency of 'green leafy vegetables', 'nuts and seeds' and 'fish & seafood' increased significantly (from 2 to 6). In contrary, the consumption frequency of 'other vegetables' decreased in the follow-up survey significantly from 11 to 7. Like in the HDDS, high seasonal fluctuations concerning the consumption frequencies, were revealed for the food groups 'starchy plants' (+2.5), 'green leafy vegetables' (+4), 'legumes and pulses' (-5), 'other vegetables' (-4) and 'fruits' (-2).

Table 3.4 Weekly consumption of the 14 FFQ food groups in Lindi; rainy vs. dry season

Food groups FFQ, weekly	Lindi Baseline	Lindi Follow-up	Trend
N, weekly	**580**	**580**	**-**
Cereals	14 (11, 14) 0 - 24	14 (12, 15) 0 – 26	0
Bread & similar products	1 (0, 3) 0 – 14	1 (0, 3) 0 – 14	0
Starchy plants	2 (1, 4) 0 – 16	4.5 (2, 7)** 0 – 20	+2.5
Legumes/Pulses	7 (4, 12) 0 – 24	2 (1, 4)** 0 – 14	-5
Green leafy vegetables	2 (0, 3) 0 – 20	6 (4, 8)** 0 – 23	+4
Other vegetables	11 (2.5, 16) 0 – 42	7 (4, 12)** 0 – 32	-4
Fruits	3 (1, 7) 0 – 28	1 (0, 3)** 0 – 29	-2
Nuts & Seeds	0 (0, 2) 0 – 14	1 (0, 3)** 0 – 18	+1
Oil & Fat	7 (2.5, 14) 0 – 28	7 (4, 7) 0 – 14	0
Fish & Seafood	1 (0, 2) 0 – 14	2 (0, 3)** 0 – 10	+1
Flesh meat & organ meat	0 (0, 1) 0 – 14	0 (0, 1) 0 – 7	0
Eggs, Milk & Milk products	0 (0, 1) 0 – 14	0 (0, 0)* 0 – 8	0
Sugar & Sweets	5 (1, 7) 0 – 30	3 (1, 7)** 0 – 43	-2
Tea, Coffee & Alcoholic Beverages	5 (2, 7) 0 – 23	5 (2, 7) 0 – 21	0

Figures are median (25th and 75th percentile) and minimum - maximum of food group consumption per week, all such values. P-Values: Wilcoxon signed ranks test, *p<0.05 and ** p< 0.001

In the baseline survey in Lindi, when the prevalence of anemia was lower than in the follow-up survey in the rainy season (27.1% vs. 34.3%), the farmers consumed significantly more frequently ‘legumes and pulses’, ‘other vegetables’ and ‘fruits’ than in the follow-up survey in March [Table 3.5]. In contrast, anemic and nonanemic farmers consumed significantly more green leafy vegetables in the rainy season than in the dry season, the only food group consumed more frequently in the rainy season.
Anemic farmers consumed significantly less frequently ‘sugar and sweets’ (4 vs. 5 at baseline and 3 vs. 4 at follow-up), ‘bread and similar products’ (0 vs. 1 at both seasons), ‘flesh meat and organ meat’ (only at baseline), ‘fish and seafood’ (1 vs. 2 at follow-up) and ‘tea coffee and alcoholic beverages’ (4 vs. 5 at follow-up) than non-anemic farmers. Evident for both survey times, anemic farmers consumed less frequently ‘other vegetables’ than non-anemic pigeon pea farmers (10 vs. 13 and 6 vs. 8), being significant in the follow-up survey.

Consistent for both seasons in Lindi, significant positive correlations between the hemoglobin concentration and the consumption frequency of ‘bread and similar products’, ‘other vegetables’, ‘oil and fat’, and ‘flesh meat and organ meat’, were detected [Table 3. 6]. In March, the hemoglobin concentration correlated significantly and positively with the consumption frequency of ‘sugar and sweets’ (R_2=0.151) and ‘tea, coffee and alcoholic beverages’ (R_2=0.129). The weekly consumption of ‘green leafy vegetables’ was inversely correlated with hemoglobin in the follow-up survey in March (R_2=-0.116).

Table 3.5 Weekly consumption of FFQ food groups in anemic vs non-anemic farmers by seasons in Lindi

FFQ Food groups, weekly	Lindi, Baseline survey (July 2019), N=670		Lindi, Follow-up survey (March 2020), N=580	
	Anemic	Non-anemic	Anemic	Non-anemic
%, (N)	27.1, (182)	72.9, (488)	34.3, (199)	65.7, (381)
Cereals	14 (10, 14) 0 - 24	14 (12, 14) 0.5 - 24	14 (11, 14) 1 - 24	14 (11, 14) 0 - 24
Bread & similar products	0** (0, 2) 0 - 14	1 (0, 3) 0 - 14	0 (0, 3) 0 - 14	1 (0, 4) 0 - 14
Starchy plants	2 (1, 4) 0 - 12	2 (1, 4) 0 - 21	2* (1, 4) 0 - 10	2 (1, 4) 0 - 16
Legumes/Pulses	7* (5, 14) 0 - 16	7 (4, 11) 0 - 24	2 (1, 4) 0 - 14	2 (1, 4) 0 - 12
Green leafy vegetables	2 (0, 3) 0 - 12	2 (0, 3) 0 - 20	7** (4, 9) 0 - 23	6 (4, 8) 0 - 20
Other vegetables	10 (2, 17) 0 - 36	13 (4, 16) 0 - 42	6** (3, 10) 0 - 28	8 (4, 13) 0 - 32
Fruits	2 (0, 7) 0 - 28	3 (1, 7) 0 - 26	1 (0, 3) 0 - 17	1 (0, 3) 0 - 29
Nuts & Seeds	0 (0, 2) 0 - 14	0 (0, 2) 0 - 14	1 (0, 3) 0 - 14	1 (0, 3) 0 - 18
Oil & Fat	7 (1, 12) 0 - 28	7 (3, 14) 0 - 28	7* (3, 7) 0 - 14	7 (5, 8) 0 - 14
Fish & Seafood	1* (0, 2) 0 - 14	1 (0, 2) 0 - 22	1** (0, 3) 0 - 7	2 (1, 3) 0 - 10
Flesh meat & organ meat	0* (0, 0) 0 - 14	0 (0, 1) 0 - 12	0 (0, 0) 0 - 4	0 (0, 1) 0 - 7
Eggs, Milk & Milk products	0 (0, 1) 0 - 8	0 (0, 1) 0 - 14	0 (0, 0) 0 - 7	0 (0, 0) 0 - 8
Sugar & Sweets	4* (0, 7) 0 - 15	5 (2, 7) 0 - 30	3** (1, 6) 0 - 14	4 (1, 7) 0 - 43
Tea, Coffee & Alcoholic Beverages	5 (1, 7) 0 - 23	5.5 (2, 7) 0 - 21	4* (2, 7) 0 - 18	5 (2, 7) 0 - 21

Figures are median (25th and 75th percentile) and minimum - maximum of food group consumption per week, all such values. P Values: Mann-Whitney-U (median) test. P-Values: *<0.05, **<0.001. The cutoff for anemia is at hemoglobin concentrations <13 g/dL for men, <12 g/dL for non-pregnant women and for <11g/dL for pregnant women.

Table 3.6 Correlations (Spearman) of the hemoglobin concentration with frequency of consumed food groups by season

Food groups, FFQ	Anemia, Tanzania, Lindi	
	Baseline, July N=580	Follow-up, March N=580
	R_1	**R_2**
Cereals	-0.046	0.028
Bread & similar products	**0.141****	**0.107***
Starchy plants	0.065	-0.044
Legumes/Pulses	-0.080	0.050
Green leafy vegetables	0.056	**-0.116****
Other vegetables	**0.099***	**0.133****
Fruits	0.054	0.049
Nuts & Seeds	**0.101***	0.064
Oil & Fat	**0.085***	**0.094***
Fish & Seafood	0.050	**0.133****
Flesh meat & organ meat	**0.096***	**0.123****
Eggs, Milk & Milk products	0.023	0.040
Sugar & Sweets	0.078	**0.151*****
Tea, Coffee & Alcoholic Beverages	0.061	**0.129****

Correlations and p-values were measured by using the Spearman-Test. Values represent the correlation between the hemoglobin concentration and the weekly consumption frequency of FFQ food groups; R_1= correlation coefficient for the baseline survey. R_2= correlation coefficient for the follow-up survey. P-Values: *<0.05, **<0.01, ***<0.001

Valid for both seasons in Lindi, pre-obese and obese farmers consumed more frequently ‘bread and similar products’, ‘sugar and sweets’, and ‘tea, coffee and alcoholic beverages’ than underweight participants [Table 3.7]. Whereas, consistent for both seasons in Lindi, the weekly consumption frequency of ‘cereals’, ‘fruits’, ‘fish and seafood’, and ‘meat’ did not vary significantly between the four different BMI-groups. During the rainy season all farmers, irrespective of their BMI, consumed ‘starchy plants’ and of ‘green leafy vegetables’ more frequently than during the dry season.

The median consumption frequency of ‘legumes and pulses’ was significantly higher during the dry season for farmers with a BMI below 18.5 than for all other BMI groups (8 vs. 7,7,6), and showed overall a lower consumption frequency during the rainy season compared to the dry season. However, there was no difference in the rainy season in the weekly consumption frequency of ‘legumes and pulses’ between all four BMI groups.

Significant positive correlations between the BMI and the consumption frequency of ‘bread and similar products’ (R_1=0.083; R_2=0,177), ‘other vegetables’ (R_1=0.131, R_2=0.128), ‘oil and fat’ (R_1=0.130, R_2=0.132) and ‘sugar and sweets’ (R_1=0.164, R_2=0.147) were measured during both seasons [Table 3.8]. In the dry season in Lindi, the BMI correlated positively with the consumption frequency of ‘starchy plants’ (R1=0.090), but inversely in the rainy season (R2=-0.119). In the dry season, another inverse correlation between the consumption frequency of ‘legumes and pulses’ and the BMI was shown (R1=-0.123).

Table 3.7 Weekly consumption of FFQ food groups by BMI categories during baseline vs. Follow-up study in Lindi, Tanzania

Food groups, FFQ, weekly	Underweight	Normal weight	Pre-obese	Obese
% (N), N=670	**10.0 (67)**	**67.3 (451)**	**16.1 (108)**	**6.6 (44)**
Cereals, (BL)	14 (10, 14) 3 - 21	14 (11, 14) 0 - 24	14 (10.5, 14) 4 - 20	14 (13, 14) 0.5 - 21
Cereals, (FU)	14 (14, 14) 5 - 24	14 (12, 15) 0 - 26	14 (11, 15) 4 - 19	14 (12, 15) 7 - 21
Bread & similar products, (BL)	0 (0, 2)[a] 0 - 7	1 (0, 3)[b] 0 – 14	1 (0, 3)[a,b] 0 - 14	**2** (0, 3)[b] 0 - 9
Bread & similar products, (FU)	0 (0, 2)[a] 0 - 6	1 (0, 3)[b] 0 - 14	**2** (0, 4)[b] 0 - 12	**2** (0, 4)[b] 0 - 9
Starchy plants, (BL)	2 (0, 3)[a] 0 - 8	2 (1, 4)[b,c] 0 - 21	**3** (1, 4.5)[c] 0 - 14	2 (1, 3)[a,b] 0 - 7
Starchy plants, (FU)	**5** (3, 9)[a] 0 - 14	**5** (2, 7)[a] 0 - 20	4 (2, 6)[a,b] 0 - 16	3 (2, 5)[b] 0 - 11
Legumes/ Pulses, (BL)	**8** (6, 14)[a] 1 - 20	7 (4, 12)[b] 0 - 24	7 (4, 10.5)[b] 1 - 17	6 (3, 11)[b] 0 - 18
Legumes/ Pulses, (FU)	2 (0, 4) 0 - 11	2 (1, 4.35) 0 - 14	2 (1, 4) 0 - 12	2 (1, 4) 0 - 10
Green leafy vegetables, (BL)	2 (0, 3) 0 - 17	2 (0, 3) 0 - 20	2 (0, 3) 0 - 14	1.5 (0, 2) 0 - 8
Green leafy vegetables, (FU)	7 (5, 9)[a] 1 - 20	6 (4, 8)[a,b] 0 - 23	6 (3, 7)[b] 0 - 15	5 (4, 8)[a,b] 0 - 15
Other vegetables, (BL)	7 (1, 16)[a] 0 - 32	11 (3, 16)[a,b] 0 - 42	**14** (5, 17)[b] 0 - 33	12 (3, 24)[a,b] 0 - 32
Other vegetables, (FU)	5 (1, 11)[a] 0 - 28	7 (4, 11)[a] 0 - 32	**8.5** (4, 12)[a,b] 0 - 28	**10** (6, 15)[b] 0 - 28
Fruits, (BL)	2 (0, 7) 0 - 28	3 (1, 7) 0 - 26	3 (1, 7) 0 - 21	3 (1, 5) 0 - 21
Fruits, (FU)	0 (0, 3) 0 - 11	1 (0, 3) 0 - 29	1 (0, 4) 0 - 14	0 (0, 2) 0 - 12
Nuts & Seeds, (BL)	0 (0, 1)[a] 0 - 12	0 (0, 2)[a,b] 0 - 14	0 (0, 2)[a] 0 - 10	1 (0, 3)[b] 0 - 8
Nuts & Seeds, (FU)	0 (0, 2) 0 - 8	1 (0, 3) 0 - 18	1 (0, 3) 0 - 8	1 (0, 3) 0 - 7
Oil & Fat, (BL)	7 (0.75, 10)[a] 0 - 14	7 (2, 14)[a] 0 - 21	7 (2.5, 14)[a,b] 0 - 28	**7** (6.5, 14)[b] 0 – 14.5

Oil & Fat, (FU)	6 (2, 8)[a] 0 - 14	7 (4, 7)[a] 0 - 14	7 (5, 7)[b] 0 - 14	7 (6, 10)[b] 0 - 14
Fish & Seafood, (BL)	1 (0, 2) 0 - 7	1 (0, 2) 0 - 22	1 (0, 2) 0 - 7	1.5 (0, 2) 0 - 14
Fish & Seafood, (FU)	1 (0, 2) 0 - 7	2 (0, 3) 0 - 10	2 (0, 3) 0 - 7	2 (1, 3) 0 - 5
Flesh meat & organ meat, (BL)	0 (0, 1) 0 - 3	0 (0, 1) 0 - 14	0 (0, 1) 0 - 7	0 (0, 1) 0 - 12
Flesh meat & organ meat, (FU)	0 (0, 0) 0 - 3	0 (0, 1) 0 - 7	0 (0, 0.5) 0 - 6	0 (0, 1) 0 - 5
Eggs, Milk & Milk products, (BL)	0 (0, 0) 0 - 7	0 (0, 1) 0 - 14	0 (0, 1) 0 - 7	0 (0, 1) 0 - 9
Eggs, Milk & Milk products, (FU)	0 (0, 0)[a] 0 - 3	0 (0, 0)[a,b] 0 - 8	0 (0, 0)[a,b] 0 - 8	**0** (0, 1)[b] 0 - 8
Sugar & Sweets, (BL)	3 (0, 7)[a] 0 - 14	5 (1, 7)[b] 0 - 17	**6** (2, 7)[b] 0 - 30	**6.5** (2, 7)[b] 0 - 10
Sugar & Sweets, (FU)	2 (0, 4)[a] 0 - 14	3 (1, 7)[b] 0 - 30	**4** (1, 7)[b] 0 - 43	**5** (2, 7)[b] 0 - 16
Tea, Coffee & Alcoholic Beverages, (BL)	3 (1, 7)[a] 0 - 21	5 (2, 7)[b] 0 - 23	**7** (2, 7)[b] 0 - 14	5.5 (2.5, 7)[a,b] 0 - 9
Tea, Coffee & Alcoholic Beverages, (FU)	3 (1, 7)[a] 0 - 18	5 (2, 7)[a,b] 0 - 21	5 (3, 7)[a,b] 0 - 16	**7** (3, 7)[b] 0 - 16

Figures are median (25th and 75th percentile) and minimum - maximum of food group consumption per week, all such values.
P Values: Kruskall Wallis and multiple pairwise unadjusted comparison (Mann-Whitney U tests). Values within a row not sharing a common superscript letter (a,b) are significantly different at p<0.05. Underweight: BMI<18.5; Normal weight: BMI 18.5-24.9; Pre-obese: BMI 25-29.9; Obese: BMI≥30 [72].

Table 3.8 Correlations (Spearman) between the FFQ food group consumption frequency and the BMI in Lindi by season

Food groups, FFQ	BMI, Tanzania, Lindi	
	Baseline, July N=580	Follow-up, March N=580
	R_1	R_2
Cereals	0.044	0.014
Bread & similar products	**0.083***	**0.177*****
Starchy plants	**0.090***	**-0.119****
Legumes/Pulses	**-0.123****	0.017
Green leafy vegetables	-0.010	-0.077
Other vegetables	**0.131****	**0.128****
Fruits	**0.132****	0.005
Nuts & Seeds	0.078	0.051
Oil & Fat	**0.130****	**0.132****
Fish & Seafood	**0.099***	0.047
Flesh meat & organ meat	0.038	0.023
Eggs, Milk & Milk products	**0.089***	**0.104***
Sugar & Sweets	**0.164*****	**0.147*****
Tea, Coffee & Alcoholic Beverages	**0.100***	**0.100***

Correlations and p-values were measured by using the Spearman-Test. Values represent the correlation between the BMI and the weekly consumption frequency of FFQ food groups; R_1= correlation coefficient for the baseline survey. R_2= correlation coefficient for the follow-up survey. P-Values: *<0.05, **<0.01, ***<0.001.

3.3 ‘’High Prevalence of Overweight and Its Association with Mid-Upper Arm Circumference among Female and Male Farmers in Tanzania and Mozambique’’

Laila Eleraky, Ramula Issa, Sónia Maciel, Hadijah Mbwana, Constance Rybak, Jan Frank, Wolfgang Stuetz (2021): This article has been published in: *International Journal of Environmental Research and Public Health* 2021, 18, 9128.

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High Prevalence of Overweight and Its Association with Mid-Upper Arm Circumference among Female and Male Farmers in Tanzania and Mozambique

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Abstract: The increasing prevalence of overweight/obesity may already have reached the farmers in Tanzania and Mozambique. Here, the measurement of the mid-upper-arm-circumference (MUAC) could become a simple and sensitive tool for early detection of at-risk groups of overweight as well as underweight. Body Mass Index (BMI) and MUAC of female and male farmers (n = 2106) from different regions of Tanzania and the Zambézia province, Mozambique, were analyzed by region, sex, age, and correlates. MUAC cut-offs, calculated via BMI cut-offs (<18.5, ≥25, and ≥30 kg/m^2), and multiple linear regression (MLR), compared to those selected by highest Youden's index (YI) value, were assessed. The study showed an overall higher prevalence of overweight (19%) than underweight (10%) due to the high number of overweight female farmers (up to 35%) in southern Tanzania. BMI, which was mainly and positively predicted by MUAC, was higher in Tanzania and among female farmers, and decreased significantly from the age of ≥65 years. MUAC cut-offs of <24 cm and ≥30.5 cm, calculated by MLR, detected 55% of farmers being underweight and 74% being overweight, with a specificity of 96%; the higher cut-off <25 cm and lower cut-off ≥29 cm, each selected according to YI, consequently detected more underweight (80%) and overweight farmers (91%), but on the basis of a lower specificity (87–88%). Overweight was evident among female farmers in East Africa. MUAC cut-offs, whether defined via linear regression or Youden's Index, could prove to be easy-to-use tools for large-scale screenings of both underweight and overweight.

Keywords: overweight; body mass index; mid-upper arm circumference; Tanzania; Mozambique; Africa

1. Introduction

As early as the 1990s, the World Health Organization underlined that overweight and obesity are becoming a major health problem in developing countries, especially among adult women [1]. A meta-analysis from 2016 with more than 19.2 million adult women and men from 186 different countries revealed an increase of global age-standardised BMI from 1975 to 2014 in both sexes: the prevalence of obesity (BMI ≥ 30 kg/m^2) increased from 3.2% to 10.8% in men, and from 6.4% to 14.9% in women; compared with the increase in obesity, the prevalence of underweight decreased (by a smaller amount) from 13.8% to 8.8% in men and from 14.6% to 9.7% in women [2]. Adequate nutritional status is defined as the physiological state of an individual that results from balance between nutrient intake and the specific requirements of the human body [3]. Malnutrition refers to all forms of inadequate nutrition, including undernutrition (BMI < 18.5 kg/m^2), overweight

(BMI ≥ 25 kg/m^2, pre-obesity and obesity), obesity (BMI ≥ 30 kg/m^2), and micronutrient malnutrition [4,5]. A nutrition transition from undernutrition towards overweight and obesity in urban and rural areas of Tanzania and Mozambique was attributed to changes in dietary patterns [6,7]. This transition is characterised by a high consumption of food items that are high in fats, refined carbohydrates, and sugars, and a low intake of vegetables and fibres [6]. A high prevalence of overweight has been previously reported among Mozambican adolescent girls living in rural areas [7]. Similarly, the prevalence of pre-obesity (23%) and obesity (17%) was high in females and males from the Kilimanjaro region in Tanzania, where women were more than five times as likely (adjusted OR 5.5 (3.1–9.8)) to be overweight (BMI ≥ 25 kg/m^2) compared to men [8].

The nutritional status is usually assessed by measuring weight and height and the calculation of the body mass index (BMI) [9]. The mid-upper-arm circumference (MUAC), which is the circumference of the left arm midway between the tip of the elbow and the tip of the shoulder, was repeatedly validated as a fast and reliable approach for assessing the nutritional status of a population [10–12]. Nevertheless, the MUAC is still not established as an alternative method and indicator of nutritional status and malnutrition beside the BMI. A systematic review of 47 cross-sectional and longitudinal studies revealed low maternal MUAC as a predictor for poor pregnancy outcomes (low birth weight), and showed a strong association of low MUAC (<22, 23, 24 cm) with low BMI (<18.5 kg/m^2) among adults in low-income countries across Africa and Asia [11]. A meta-analysis compiling 17 datasets from Africa, Asia, and North and South America found a strong positive correlation between MUAC and BMI and that MUAC cut-offs in the range of 23.0 to <25.5 cm could serve as appropriate indicators for low BMI, while a MUAC < 24.0 cm meets the criteria across various subpopulations when assessed against BMI < 18.5 kg/m^2 [13]. The strong positive correlation between MUAC and BMI and its role as a valuable anthropometric marker and nutritional status indicator for undernutrition was confirmed in studies among adolescent girls in Central Mozambique and adults in Bangladesh [14,15]. A multi-cross-sectional study in Nigeria, South Africa, Uganda, and Tanzania (n = 1463) revealed a high incidence of overweight and obesity, which far surpassed and replaced undernutrition as a public health problem in both rural and urban areas [16]; therefore, MUAC and appropriate MUAC cut-offs could be a simple and sensitive tool for early detection of at risk-groups of overweight as well as underweight.

In the present study, we assessed anthropometrics of female and male farmers from the baseline surveys of the Scale-N and the Vegi-Leg projects. Both projects aim to ameliorate the nutritional status of small-scale farmers through tailored nutrition-sensitive interventions. The Scale-N project aimed to achieve food and nutrition security of small-scale farmers in Central Tanzania by the development of nutrition-sensitive and diversified agricultural production methods and improvement of nutritional behavior [17–19]; The Vegi-Leg project operates in Lindi region, South Tanzania, and in Gurue, Zambézia province of Mozambique among pigeon pea *(Cajanus cajan)* farmers, in areas with a high prevalence of anaemia and micronutrient deficiencies with the aim of safeguarding perennial nutrition security through the development of low-cost processing technologies for nutrient-dense products from pigeon peas and dark green leafy vegetables [20–22].

The objectives of the present study were to analyze and evaluate (1) the nutritional status among female and male farmers in Tanzania and Mozambique using BMI and MUAC, (2) the correlations between BMI with MUAC considering sex, study region, and age, and (3) MUAC cut-offs as appropriate markers to identify undernutrition as well as overnutrition.

2. Materials and Methods

2.1. Study Population and Design

The study population included female farmers of the Scale-N and female and male pigeon pea farmers of the Vegi-Leg projects. A total of 666 female self-sufficient small-scale farmers (mothers and/or caregivers) aged 20 to 75 years, 85% of whom were of reproductive age (15–49 years) and 3.6% ≥65 years, were enrolled in the Scale-N project from July to August 2016 in four different villages in the Dodoma and Morogoro regions, Central Tanzania [17–19]. Between July and August 2019, the Vegi-Leg project enrolled 673 farmers from two villages in the Lindi region of Southern Tanzania, aged 16 to 89 years, and 870 farmers from two villages in the Gurué district of Zambézia province in Central Mozambique, aged 18 to 65 years (Figure 1) [20]; of the farmers from Lindi and Gurué, 16% and 3.7% were ≥65 years old, respectively, while 64% and 81% of the female farmers were of reproductive age.

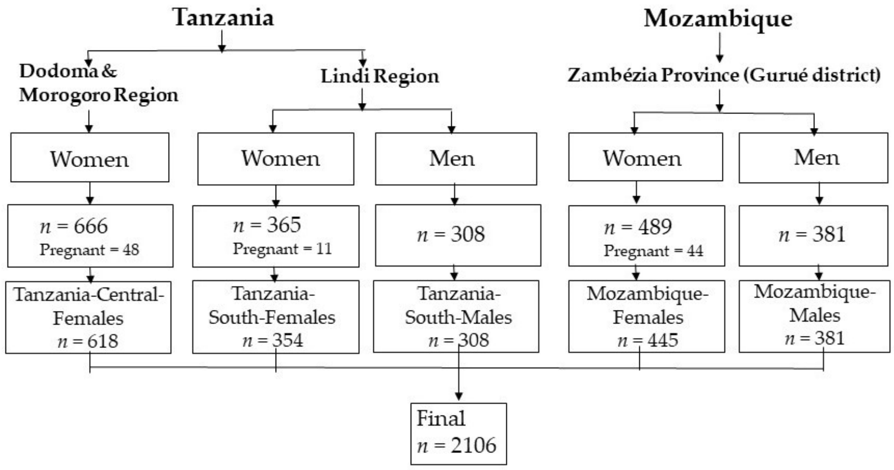

Figure 1. Study population: female and male farmers from Tanzania and Mozambique.

The surveys were carried out according to the guidelines laid down in the 'Declaration of Helsinki' and approved by the National Institute for Medical Research and the Ministry of Health, Community Development, Gender, Elderly and Children in Dar es Salaam (NIMR/HQ/R.8a/Vol. IX/2226) and Dodoma, Tanzania (NIMR/HQ/R.8a/Vol.IX/ 3040), and ethically reviewed by the National Bioethics Committee for Health of Mozambique (IRB00002657, Ref 370/CNBS/19). Written informed consent was obtained from all farmers. After excluding 103 pregnant women, anthropometric data from a total of 2106 female and male farmers from the different provinces in Tanzania and Mozambique were included in the present investigation.

2.2. Anthropometric Measurements

Weight, height, and mid-upper arm circumference (MUAC) were measured using electronic or mechanical floor scales (Seca 874 in Tanzania, Seca 750 in Mozambique, Seca GmbH & Co KG Hamburg, Germany), a wooden (UNICEF) or plastic stadiometer (Seca 213, Seca GmbH & Co KG Hamburg, Germany), and a standard MUAC tape (UNICEF in Tanzania or Seca 201 in Mozambique), respectively. Weight was recorded to the nearest 0.1 kg, while height and MUAC were measured to the nearest 0.1 cm. MUAC was measured on the left arm. Body mass index (BMI) was calculated from weight and height measured at admission; standard cut-offs for underweight (<18.5 kg/m^2), overweight (≥25 kg/m^2), obesity (≥30 kg/m^2), and low MUAC for adults (<24 cm) were used according to WHO and FANTA (Food and Nutrition Technical Assistance) instructions [4,19]. The term overweight (or crude overweight) is used to define a BMI ≥ 25 kg/m^2, while pre-obesity refers to a BMI range from ≥25 kg/m^2 to <30 kg/m^2 [23].

2.3. Statistical Analyses

Age and anthropometrics (weight, height, BMI) were described using medians and interquartile ranges (IQR: 25% and 75% percentile) for continuous variables and frequencies (%) for categorical data. Differences of age and anthropometrics between study regions by sex were compared using Kruskal–Wallis and post-hoc Dunn–Bonferroni test or Chi Square tests (prevalence), as appropriate.

The association of BMI with MUAC for all farmers and by region and sex was shown via scatter plots and corresponding coefficients of determination (R^2), while individual relationships of BMI with MUAC, weight, height, age, and elders (>65 years) were presented and evaluated using Spearman's rank correlation coefficients. Multiple linear regression analysis (with a forward stepwise approach) was applied to identify independent and significant predictors of BMI. The resulting formula (BMI = 0.974 × MUAC + 0.834 × TZ + 0.374 × female + 0.552 × age ≥65 y − 5.447) with MUAC as the main predictor was applied to calculate MUAC cut-offs for all studied farmers, and by country, sex, and the elderly (≥65 years) using the established BMI cut-offs (<18.5, ≥25.0, and ≥30.0 kg/m^2) for underweight, overweight and obesity [23,24]. Matches (percent of joint true positive cases) between MUAC and BMI categories as well as the sensitivity (true positive/ (true positive + false negative)) and specificity (true negative/(true negative + false positive) of the calculated MUAC cut-offs in identifying BMI categories were compared with matches, sensitivity and specificity of MUAC cut-offs (and respective categories) selected according to the highest Youden's Index values (YI = sensitivity + specificity − 1). All statistical analyses were conducted using SPSS version 20; two-tailed *p*-values < 0.05 were considered statistically significant.

3. Results

A total of 2106 non-pregnant female and male farmers were assessed on anthropometrics (Table 1). The participants consisted of 618 women from the Scale-N baseline study in central Tanzania and 1488 female and male farmers from the Vegi-Leg project in Lindi region, Tanzania, and Zambézia province, Mozambique. The total study population had a median age of 39 years and consisted of 67% female farmers. Farmers from Lindi region, South Tanzania, had the highest median age, and participating men in Lindi region and Zambézia province were older than the corresponding women.

The median weight and height of all farmers was 52.8 kg and 155.6 cm; male farmers were heavier (53.9 vs. 52.2 kg) and significantly taller (162 vs. 153.4 cm), but had a significantly lower BMI and MUAC than female farmers (Table 1). In terms of BMI categories, 18.8% were overweight, including 4.6% with obesity, compared to 10.3% of all farmers who were underweight. In both countries, there was a higher prevalence of pre-obesity and obesity, and thus a significantly higher prevalence of overweight among female compared to male farmers. Further, overweight in female farmers was higher in Tanzania than in Mozambique, with the highest prevalence among female farmers of the Lindi province in South Tanzania (35% with BMI > 25 kg/m^2). One in four (26%) and one in three (35%) female farmers in central and southern Tanzania, respectively, was overweight. In contrary, 15% of the female Mozambican farmers and less than 9% of all male farmers were overweight.

The overall median MUAC was 27.2 cm, ranging from 26.4 cm for male farmers from Mozambique to 28.1 cm for female farmers from Lindi; accordingly, male farmers had a significantly higher prevalence of low MUAC (<24 cm) compared to female farmers, in Tanzania as well as in Mozambique. The 80th and 95th percentiles of MUAC were 30 and 33.5 cm, respectively; these cut-offs showed a significantly higher prevalence of high MUAC among female versus male farmers, particularly evident in Lindi, Tanzania.

Linear regression analysis revealed strong positive correlations of BMI with MUAC within the entire study population as well as the individual subgroups in terms of region and sex (Figure 2). The coefficient of determination (R^2) was higher in Tanzanian than in Mozambican farmers and overall higher among female farmers in both countries than for corresponding male farmers. Accordingly, the highest coefficients of determination were shown for the female farmers of Tanzania (R^2 = 0.842 and 0.791), who also represented the groups with the highest prevalence of overweight; in contrary, the lowest coefficient was shown for male farmers from Mozambique (R^2 = 0.532), who had the lowest prevalence of overweight.

Table 1. Characteristics and anthropometrics of the farmers during baseline studies.

	All (*n* = 2106)	**Tanzania-Centre-Females (*n* = 618)**	**Tanzania-South-Females (*n* = 354)**	**Tanzania-South-Males (*n* = 308)**	**Mozambique-Females (*n* = 445)**	**Mozambique-Males (*n* = 381)**
Age [years] [1]	39.0 (29.0, 49.0)	36.0 [a] (30.0, 44.0)	42.0 [b] (32.0, 58.0)	44.0 [b] (32.0, 58.7)	35.0 [c] (25.0, 45.0)	38.0 [d] (27.0, 51.0)
Age ≥ 65 years [2]	7.5 (159)	3.6 (22)	15.8 (56)	16.2 (50)	2.9 (13)	4.7 (18)
Weight [kg] [1]	52.8 (47.9, 59.6)	53.3 [a] (48.1, 60.5)	53.6 [a,b] (47.6, 62.2)	55.0 [b] (49.3, 61.2)	50.2 [c] (45.9, 56.0)	53.0 [a] (49.9, 59.0)
Height [cm] [1]	155.6 (151.1, 161.0)	154.5 [a] (151.0, 158.1)	151.7 [b] (148.2, 155.5)	162.1 [c] (158.0, 166.7)	153.1 [d] (148.9, 156.8)	162.0 [c] (157.1, 166.6)
BMI [kg/m^2] [1]	21.5 (19.7, 24.0)	22.2 [a] (20.4, 25.0)	23.4 [b] (20.9, 26.3)	21.0 [c] (19.5, 22.7)	21.3 [d] (19.8, 23.7)	20.3 [e] (19.1, 21.7)
BMI categories [2]						
<18.5 kg/m^2	10.3 (216)	6.3 (39)	6.8 (24)	13.0 (40)	11.2 (50)	16.5 (63)
18.5–24.9 kg/m^2	71.0 (1495)	68.1 (421)	58.5 (207)	78.6 (242)	73.0 (325)	78.7 (300)
25–29.9 kg/m^2	14.2 (299)	19.1 (118)	23.4 (83)	7.5 (23)	13.5 (60)	3.9 (15)
≥30 kg/m^2	4.6 (96)	6.5 (40)	11.3 (40)	1.0 (3)	2.2 (10)	0.8 (3)
BMI ≥ 25 kg/m^2	18.8 (395)	25.6 (158) [a]	34.7 (123) [b]	8.5 (26) [c]	15.7 (70) [d]	4.7 (18) [e]
MUAC cut-offs [2]						
MUAC < 24 cm	9.4 (199)	7.4 (46) [a]	7.6 (27) [a]	14.9 (46) [b]	6.1 (27) [a]	13.9 (53) [b]
MUAC ≥ 30 cm	20.7 (435)	24.1 (149) [a]	33.6 (119) [b]	10.1 (31) [c]	23.1 (103) [a]	8.7 (33) [c]
MUAC ≥ 33.5 cm	5.4 (114)	7.4 (46) [a,c]	11.0 (39) [a]	1.3 (4) [b]	4.7 (21) [c]	1.0 (4) [b]

Data are median (25th and 75th percentile) [1], or percentage (number of farmers) [2], all such values. Differences between individual groups were assessed by Kruskall–Wallis and post-hoc Dunn–Bonferroni tests (pairwise comparisons) or Chi Square tests; values within a row not sharing a common superscript letter [(a,b,c,d,e)] are significantly different at $p < 0.05$. Chi Square tests (pravelences) within BMI categories: $p < 0.001$. BMI ≥ 25 kg/m^2: overweight; MUAC = mid-upper arm circumference; BMI = body mass index; MUAC ≥ 30 cm and ≥ 33.5 cm representing 80th and 95th percentile, respectively.

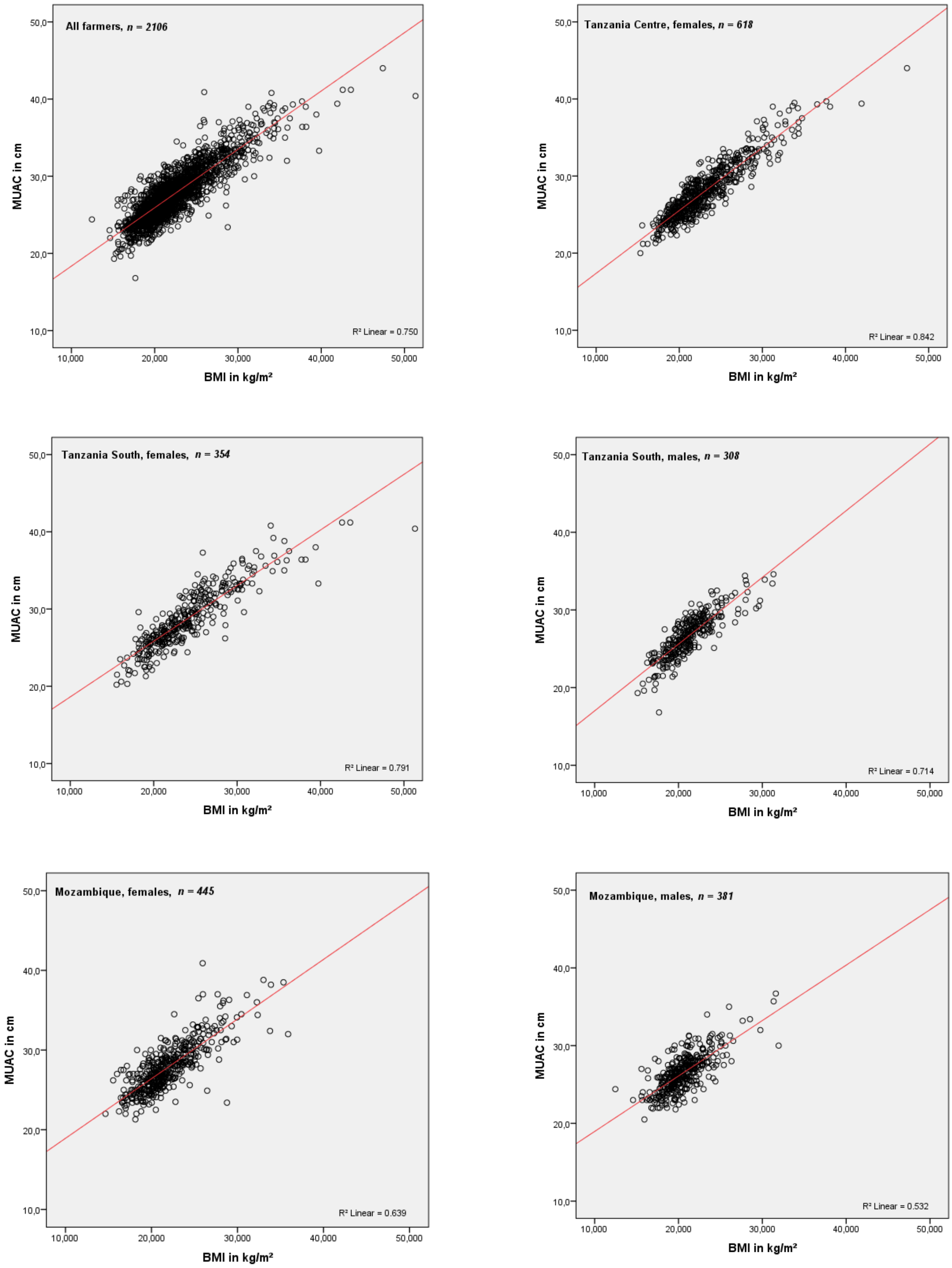

Figure 2. Association of mid-upper arm circumference (MUAC) with body mass index (BMI) in farmers and the respective sub-groups by sex and region.

The correlations of BMI with MUAC, weight, height, age, and age ≥ 65 years among all farmers and clustered by sex and region are shown in Table 2: In the entire study population and both countries, the BMI correlated strongly and positively with MUAC (r = 0.837, 0.885, and 0.758). The correlations were stronger in Tanzania than in Mozambique and in female than in male farmers. BMI was inversely correlated with height, age and the elderly (≥65 years); the inverse correlation of BMI with age and elderly was strongest in male farmers from Tanzania.

Table 2. Correlation of BMI with MUAC, weight, height, age, and age ≥ 65 among all farmers, and clustered by sex and country.

BMI [kg/m²]	MUAC [cm]	Weight [kg]	Height [cm]	Age [years]	Age ≥ 65 y
All, *n* = 2106	0.837 **	0.800 **	−0.154 **	−0.068	−0.098 **
All-Females, *n* = 1417	0.858 **	0.886 **	−0.034	−0.026	−0.053 *
All-Males, *n* = 689	0.774 **	0.791 **	0.038	−0.102 **	−0.154 **
Tanzania, *n* = 1280	0.885 **	0.833 **	−0.135 **	−0.145 **	−0.161 **
TZ-Females, *n* = 972	0.895 **	0.890 **	−0.055	−0.080 *	−0.100 **
TZ-Males, *n* = 308	0.852 **	0.832 **	0.096	−0.255 **	−0.259 **
Mozambique, *n* = 826	0.758 **	0.731 **	−0.150 *	−0.014	−0.027
MZ-Females, *n* = 445	0.786 **	0.867 **	−0.016	0.034	0.042
MZ-Males, *n* = 381	0.703 **	0.743 **	−0.016	−0.035	−0.079

Spearman correlations, * $p < 0.05$; ** $p < 0.001$; TZ= Tanzania; MZ= Mozambique.

Multiple linear regression analysis revealed MUAC as a decisive and main predictor of BMI (Table 3). The MUAC was highly positively associated with BMI (partial r = 0.862). Further country (Tanzania vs. Mozambique), sex, and the elderly (age ≥65 years) were significantly associated with BMI in the final 'adjusted' model.

Table 3. Multiple linear regression analyses assessing predictors of BMI [kg/m²].

	Beta	95% CI	*R* Zero-Order	*R* Partial	*p* Value
(constant)	−5.447	−6.117–−4.777			
MUAC, cm	0.974	0.950–0.999	0.866	0.862	<0.001
Country, TZ = 1	0.834	0.667–1.001	0.209	0.209	<0.001
Sex, female = 1	0.374	0.199–0.550	0.260	0.091	<0.001
Age ≥ 65y (=1)	0.552	0.249–0.856	−0.083	0.078	<0.001

Multiple linear regression analysis (with a forward approach): MUAC [cm], region (TZ (Tanzania) = 1 vs. MZ =0), sex (female = 1 vs. male = 0), age ≥ 65years (*n* = 159; =1 vs. age < 65 = 0), and age [years] were included as independent variables in the initial model. BMI = 0.974 × MUAC + 0.834 × TZ +0.374 × female + 0.552 × age ≥ 65y − 5.447; *n* = 2106, $R^2 = 0.768$.

Table 4 show the assessments of calculated and selected MUAC cut-offs for underweight, overweight, and obesity by multiple linear regression and highest Youden's Index (YI). It also shows the slightly higher proportion of underweight among men and the elderly and again underlines the high proportion of Tanzanian women who are overweight and obese. MUAC cut-offs for malnutrition calculated by linear regression and BMI values (<18.5, ≥25, ≥30 kg/m²) ranged from 23.2 to 24.6 cm for underweight, from 29.8 to 31.2 cm for overweight, and from 35.0 to 36.4 cm for obesity in the individual subgroups, and were finally for 'all farmers' rounded to <24 cm, ≥30.5 cm, and ≥35.5 cm. These MUAC cut-offs identified 55.5%, 73.7%, and 53.1% of the farmers as underweight, overweight, and obese, respectively. MUAC cut-offs selected on the basis on the highest Youden's Index (highest sensitivity/selectivity ratio) were <25 cm, ≥29 cm, and ≥31.5 cm. The higher cut-off for undernutrition (<25 cm) and lower cut-off values for overweight (≥29 cm) and obesity (≥31.5 cm) consequently revealed higher matches of 79.8%, 91.1%, and 95.8%, respectively, while the specificity values of the selected Youden's Index cut-offs were simultaneously lower compared to those by linear regression: 87% vs. 96% for underweight, 88% vs. 96% for overweight, and 92% vs. 99% for obesity, with the consequence of more false positives and ultimately slightly overestimated numbers of matched or identified prevalence of underweight, overweight, and obesity.

Table 4. Identification of farmers with underweight, overweight, and obesity by MUAC cut-offs calculated with multiple linear regression vs. those selected by highest Youden's Index.

		MLR					Y. I.			
BMI Category	**% (*n*) BMI Category**	**MUAC by MLR**	**% (*n*) BMI Category**	**Sensiti-Vity [%]**	**Specifi-City [%]**	**Y.I.**	**% (*n*) BMI Category**	**Sensiti-Vity [%]**	**Specifi-City [%]**	**Highest Y. I.**
Underweight	**<18.5 kg/m^2**	**24 cm**	**<24 cm**	**<24 cm**	**<24 cm**	**<24 cm**	**<25 cm**	**<25 cm**	**<25 cm**	**<25 cm**
All, *n* = 2106	10.3 (216)	23.7	55.5 (120)	54.6	95.7	0.55	79.8 (168)	77.8	87.2	0.67
Tanzania, *n* = 1280	8.0 (103)	23.3	68.9 (71)	68.0	95.8	0.64	91.3 (94)	91.3	87.2	0.78
Mozambique, *n* = 826	13.7 (113)	24.2	43.4 (49)	42.5	95.5	0.38	65.5 (74)	65.5	87.2	0.53
Female, *n* = 1417	8.0 (113)	23.3	50.4 (57)	50.4	96.7	0.47	77.9 (88)	77.9	89.1	0.67
Male, *n* = 689	14.9 (103)	24.6	61.2 (63)	59.2	93.5	0.53	77.7 (80)	77.7	82.9	0.61
Age ≥ 65y, *n* = 159	22.0 (35)	23.2	80.0 (28)	77.1	85.5	0.63	91.4 (32)	91.4	75.0	0.66
Overweight	**≥25 kg/m^2**	**30.5 cm**	**≥30.5 cm**	**≥30.5 cm**	**≥30.5 cm**	**≥30.5 cm**	**≥29 cm**	**≥29 cm**	**≥29 cm**	**≥29 cm**
All, *n* = 2106	18.8 (395)	30.4	73.7 (291)	72.5	96.2	0.69	91.1 (360)	90.4	87.8	0.78
Tanzania, *n* = 1280	24.0 (307)	30.0	74.3 (228)	73.4	96.5	0.70	91.8 (282)	91.2	87.0	0.78
Mozambique, *n* = 826	10.7 (88)	30.9	71.6 (63)	69.3	95.8	0.65	88.6 (78)	88.6	87.1	0.76
Female, *n* = 1417	24.8 (351)	30.0	75.2 (264)	74.4	95.5	0.70	91.7 (322)	91.2	85.5	0.77
Male, *n* = 689	6.4 (44)	31.2	61.4 (27)	56.8	97.4	0.54	86.4 (38)	86.4	89.6	0.76
Age ≥ 65y, *n* = 159	14.5 (23)	29.8	52.2 (12)	52.2	98.5	0.51	73.9 (17)	73.9	94.1	0.68
Obesity	**≥30 kg/m^2**	**35.5 cm**	**≥35.5 cm**	**≥35.5 cm**	**≥35.5 cm**	**≥35.5 cm**	**≥31.5 cm**	**≥31.5 cm**	**≥31.5 cm**	**≥31.5 cm**
All, *n* = 2106	4.6 (96)	35.5	53.1 (51)	51.0	99.5	0.50	95.8 (92)	95.8	92.1	0.88
Tanzania, *n* = 1280	6.5 (83)	35.1	53.0 (44)	50.6	99.7	0.50	97.6 (81)	97.6	90.7	0.88
Mozambique, *n*= 826	1.6 (13)	36.0	53.8 (7)	53.8	99.1	0.53	84.6 (11)	84.6	94.5	0.79
Female, *n* = 1417	6.4 (90)	35.1	54.4 (49)	52.2	99.2	0.51	96.6 (87)	96.7	89.2	0.86
Male, *n* = 689	0.9 (6)	36.4	33.3 (2)	33.3	1	0.33	83.3 (5)	83.3	97.8	0.81
Age ≥ 65y, *n* = 159	3.8 (6)	35.0	66.7 (4)	50.0	1	0.50	83.3 (5)	83.3	97.4	0.81

Data are % (number), MUAC in cm, and sensitivity and specificity in %; MLR = multiple linear regression, Y.I. = Youden's Index; MUAC equation (n = 2106): MUAC [cm] = (BMI [kg/m^2] − 0.834 (if TZ) − 0.374 (if female) − 0.552 (if age ≥ 65 years) + 5.447)/0.974.

4. Discussion

The present study includes three cross-sectional studies and study sites and, therefore, allowed for the examination of significant associations of the BMI and its categories with MUAC in 2106 female and male small-scale farmers from different regions in Tanzania and Mozambique. The results revealed a higher prevalence of overweight (BMI $\geq$ 25 kg/m^2) than of underweight (BMI < 18.5 kg/m^2) and low MUAC (<24 cm). Female farmers from Tanzania were particularly affected by overweight and obesity, which pose serious public health concerns (26% and 35% with BMI $\geq$ 25 kg/m^2) according to WHO classification [24].

The results confirm the increasing prevalence of overweight among African women of reproductive age, as recently reported in context with metabolic risk factors (e.g., anaemia, hypertension) from 33 sub-Saharan countries, including Tanzania and Mozambique [25]. The records of over 13,000 women from Tanzania (in 2015) and over 13,500 women from Mozambique (in 2011) showed a high prevalence of overweight (pre-obesity plus obesity) with 28% and 17%, respectively [21,26]. In Tanzania, the prevalence of undernutrition in women remained unchanged between the demographic health surveys of 2004–2005 and 2015–2016, whereas the prevalence of overweight (pre-obesity and obesity) rose from 18% to 28%; this high figure is in line with the female farmers of the present study living in southern and central Tanzania, where one in three and one in four women respectively were overweight. The increasing rates of overweight (BMI $\geq$ 25 kg/m^2) and obesity (BMI $\geq$ 30 kg/m^2) are very likely related to food consumption patterns that have changed from consuming fibre-rich foods to refined foods and overall higher amounts of sugar and fats; these include high amounts of refined maize flour ('Ugali'), strongly sweetened teas, deep fried pastry products, oil and stir-fried foods, which are now easily affordable and available even in rural areas [8,27]. The dominance of cereal-based diets with insufficient fruit and vegetable consumption, despite high local food biodiversity of plant- based products, has been frequently observed in rural areas of Tanzania and Mozambique [18,28]. Surveys in African countries in the 1990s have already shown that the burden of overweight among adult women (20–49 years) was higher than that of underweight in both urban and rural areas [29]. In 1996, 28% of Tanzanian women from urban areas compared to 11% living in rural settings were overweight, while there was no significant difference in the prevalence of underweight (8.6% in urban vs. 9.6% in rural areas); the prevalence of overweight in rural areas (11%) has now doubled and tripled in the female Tanzanian farmers of the present study. Likewise, female and male adults in rural and peri-urban East Uganda (n = 1210) had an overall higher prevalence of pre-obesity (18% with BMI 25–29.99 kg/m^2) than of underweight (7%), but only because of the very high prevalence (twice that of men) of pre-obese women [30]. Similarly, a study of 435 female and male adults (between 18 and 45 years) from rural and urban communities of Nigeria revealed that the prevalence of pre-obesity (22%) was much higher and of obesity (4%) was still higher than the prevalence of underweight (2%); 40% of the urban and 30% of all rural females (twice as many women as men in both urban and rural areas) were either pre-obese or obese, and 43% of the urban and 31% of the rural females had either an increased (waist circumference $\geq$ 80 cm) or substantially increased risk (waist circumference $\geq$ 88 cm) for metabolic syndrome [31]. A study among 976 adults (606 females and 370 males) in two regional capital cities of Ghana, showed that over half of the participants from Takoradi (54%) compared to one third (38%) from Cape Coast were either pre-obese or obese; prevalence of pre-obesity and in particular of obesity was several fold higher in women than in men, and the study population had an overall high prevalence of hypertension (27.0%), diabetes (34.0%), and mild to severe anaemia (47%) [32].

The present study revealed that the MUAC as an anthropometric marker correlates strongly and positively with the BMI and its defined categories and therefore offers very good prerequisites for the detection of underweight, overweight and obesity. Our MUAC cut-offs for underweight of <24 cm calculated via multiple linear regression and of <25 cm selected via highest Youden's index identified 55% and 78%, respectively, of the farmers with underweight. MUAC cut-offs in the range of ≤23.5 to ≤25.0 cm and a proposed global MUAC cut-off of <24 cm for underweight in adults cm were recently suggested in a multicentre study combining twenty compiled datasets from different countries, including seven from Africa [12]. Although the higher cut-off at <25 cm selected by Youden's Index identified more underweight farmers, the specificity decreased from 96% to 87%, meaning the number of false positives increased and the true agreement on prevalence of underweight, compared to the lower cut-off of <24 cm calculated via linear regression, was slightly overestimated. Both MUAC cut-offs, <24 and <25 cm, identified more Tanzanian, male and the elderly (≥65 years) farmers with underweight, but again with a consequently lower specificity. A recent study in 302 female and male chronically ill and healthy adults from two urban public hospitals in Nepal suggested a MUAC cut-off of 24.5 cm (according to highest Youden's Index) for both sexes to identify underweight [33].

The present study is one of the first to evaluate specific MUAC cut-offs for the screening of overnutrition, i.e., overweight and obesity. The MUAC cut-off of ≥30.5 cm calculated via linear regression and of ≥29 cm selected via highest Youden's index were able to detect 74% and 90% of farmers, respectively, with 'general' overweight (pre-obesity plus obesity). Due to the lower 'Youden's-Index-selected' cut-off, one consequently gets more farmers and matches with overweight farmers, but simultaneously the specificity decreased from 96% to 88% and consequently, the number of false positives (farmers classified as overweight while having a BMI in the normal range) increased, and the true prevalence of overweight is slightly overestimated. More older people were reached via the MUAC cut-offs for underweight, whereas fewer older people were now reached via the MUAC cut-offs for overweight, suggesting more studies with a bigger sample size in order to assess specific MUAC-cut-offs for the elderly (≥65 years). In addition, the MUAC appears to be a more appropriate marker than BMI for assessing poor nutritional status for older people. A study among older female and male Dutch participants (n = 1307 ≥ 65 years) revealed a reduction of MUAC within a three years period, irrespective of changes in body weight, which was explained by muscular atrophy and bone loss in older age [34]. Furthermore, a study from Malawi confirms our findings that more attention to under- not overnutrition should be paid among the elderly [35]. In general, MUAC was judged more appropriate than BMI for detecting underweight in older adults with kyphosis, in individuals with changes in body composition, and in the acute phase of emergencies, e.g., adults with oedema due to protein-energy malnutrition, where thus weight gain is not related to nutritional status [36,37].

Lower cut-offs for overweight of 27.7 and 27.9 cm were also identified for male and female adolescents (15–19 years) living in Addis Ababa, Ethiopia [38]; this suggests that MUAC could be influenced by factors such as age, and thus appropriate cut-offs for specific age groups such as adolescents and the elderly should be evaluated. Furthermore, MUAC itself can be considered a valuable additional and independent marker for assessing nutritional status, rather than just a simpler method and substitute of the BMI.

In regard to obesity, the 95th percentile of our study population was 33.5 cm, very close to a proposed and by linear regression (and BMI of 30 kg/m^2) calculated 'obesity' MUAC cut-off for adults in South Africa of >33.0 cm [39]; this cut-off of 33 cm, derived from data of the national South African demographic health survey, is to our knowledge the only suggested MUAC cut-off for obesity so far. In this survey, 'African' women had a more than three times higher prevalence of obesity (32% vs. 6%) and high MUAC (31% vs. 10% > 33 cm) than African men. Our calculated MUAC cut-off of ≥35.5 cm via linear regression identified 53% and the much lower cut-off of ≥31.5 cm, selected via highest Youden's index, accordingly detected as many as 96% of obese farmers. These cut-offs were significantly different from each other with consequently different levels of agreements but also very different grades of specificities; a lower cut-off (as already shown with the MUAC cut-off for overweight) logically reaches more people but with a lower specificity, while the higher cut-off reaches fewer people, but the severe cases of obesity with a very high specificity. However, the evaluation of obesity in our study was mainly related to women, especially in southern Tanzania. Therefore, larger studies in East Africa and other African countries could confirm our results and would also allow to assess specific MUAC cut-offs of underweight, overweight and obesity by different ethnic, sex, and age groups.

The strength of the present study is the large sample size and the assessment of both women and men, who all belong to a homogenous study population, namely, small-scale farmers from different rural areas of Tanzania and Mozambique. For these farmers, we had a complete set of data on BMI and MUAC; however, one limitation of the study is that subgroups such as the elderly and those with obesity are still underrepresented for the assessment of respective specific cut-offs; in particular, for obesity as a high-risk factor for metabolic syndrome and adverse health outcomes an even larger sample for reliable cut-offs are required. A further limitation is the cross-sectional design with the associated single measurements as well as the different teams for each country and thus the probability of deviations in consistent measurement quality.

5. Conclusions

The outcomes of the present study confirm a growing and, according to the high numbers, serious health problem of over-nutrition among female small-scale farmers in Tanzania, while at the same time a relatively large number of male farmers in Tanzania and Mozambique still suffer from underweight. This is one of the first studies suggesting MUAC cut-offs to identify overweight and obesity in Africa. MUAC could be a reliable tool for the screening of both under- and overnutrition, thus making it a promising valuable anthropometric and nutritional marker in field studies, in particular where scales and stadiometers are not accessible or impractical for large-scale studies.

Author Contributions: The authors' responsibilities were as follows: S.M., H.M., C.R. and W.S. designed the research; L.E., R.I. and W.S. conducted the field study; L.E. and W.S. carried out data and statistical analysis; L.E. wrote the manuscript, and C.R., J.F. and W.S provided significant advice and critically edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The surveys were carried out according to the guidelines of the Declaration of Helsinki, ethically approved by the National Institute for Medical Research and the Ministry of Health, Community Development, Gender, Elderly and Children in Dar es Salaam (NIMR/HQ/R.8a/Vol. IX/2226) and Dodoma, Tanzania (NIMR/HQ/R.8a/Vol.IX/ 3040) and the Ethics Committee Landesärztekammer Baden-Württemberg, Stuttgart, Germany (F-2016-049), and ethically reviewed by the National Bioethics Committee for Health of Mozambique (IRB00002657, Ref 370/CNBS/19).

Informed Consent Statement: Written informed consent was obtained from all female and male farmers involved in the study.

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3.4 ‘’Potentials and limitations of a food-group based algorithm to assess dietary nutrient intake of women in rural areas in Tanzania’’

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Potentials and limitations of a food-group based algorithm to assess dietary nutrient intake of women in rural areas in Tanzania

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Potentials and limitations of a food-group based algorithm to assess dietary nutrient intake of women in rural areas in Tanzania

Abstract

The aim of this study was to evaluate the accuracy of nutrient intake assessment with the food group-based algorithm "Calculator of Inadequate Micronutrient Intake" (CIMI) in comparison to the established nutrition software NutriSurvey.

Using Food Frequency Questionnaires and 24-hrs dietary recalls of 1010 women from two rural districts in Tanzania, 23 relevant typical Tanzanian food groups were identified and subsequently the dietary protocols assessed via CIMI algorithm were compared by bivariate correlations and Bland-Altman analysis with the results of the NutriSurvey software (reference) and were set in relation to blood biomarkers of 666 participants.

CIMI and NutriSurvey calculations regarding macro- and micronutrient intakes were similar. The Bland-Altman analyses and correlation coefficients of energy (0.931), protein (0.898), iron (0.775) and zinc (0.838) confirm the agreement of both calculations.

The food group based CIMI algorithm is a practical tool to identify inadequacy of macro- and micronutrient intake at population level.

Keywords:

Validation, nutrition assessment, 24-h-recall, nutrient intake, iron, vitamin A, zinc

Introduction

Micronutrient malnutrition is common in developing countries, often due to the consumption of monotonous staple-based diets rich in foods such as cereals (maize, millet and rice) and starchy roots (cassava, potatoes and plantains). While these foods provide adequate energy, they do not contain enough bioavailable iron, vitamin A and zinc, and other micronutrients, such as folate and vitamin B1 (thiamine) (Seal *et al,.* 2005). Long-term consumption of a diet lacking micronutrient-dense foods results in hidden hunger: a chronic lack of vitamins and minerals, while being macronutrient- and energy-sufficient (Biesalski 2014, Gupta *et al,.* 2017). Although hidden hunger often goes unidentified, due to lack of clinical symptoms, its consequences can be severe. Hidden hunger can lead to irreversible mental and physical problems, poor health and productivity, and is a leading cause of childhood mortality (Biesalski 2014). Early detection of hidden hunger is therefore very important, to successfully combat micronutrient deficiencies. This can be achieved by assessing micronutrient adequacy of diets commonly consumed by at risk populations.

To identify nutrient gaps that can be used to estimate the risk for malnutrition of a certain cohort, rapid nutritional assessment tools are needed. The commonly used tools are Food Frequency Questionnaires (FFQ), Dietary Diversity scores and 24 hour recalls. With regard to FFQ and Dietary Diversity scores, the evaluation is relatively fast and uncomplicated, but the results are not suitable to calculate quantitative intakes of individual nutrients. Dietary Diversity score is only a proxy-indicator that can be used in longitudinal studies of one region (Kojima *et al,.* 2020). 24 h-recalls, on the other hand, provide detailed information about nutrient intake and dietary patterns of the study group and give an estimate of the actual food intake of an individual as recalled from memory. The collection of the data is however often very complex and time intensive (Yuan *et al,.* 2018). Afterwards the data are entered using a nutrition calculation software e.g., NutriSurvey, to calculate the macro- and micronutrient content of the foods. Data input in NutriSurvey requires the entry of each food and the amount consumed in grams, which is a time-consuming process. In addition, results of calculated intake amount of different 24 h recalls can vary greatly from day to day or seasonally.

This study used a new method, which has been developed to collect and analyse data concerning macro- and micronutrient intake in a faster and easier way. The CIMI methodological approach to estimating inadequate intake of nutrients is based on the input of the cumulative amount of foods in specific food groups rather than individual foods. Data entry in CIMI can be done during the interview, which makes it possible for the interviewer to directly provide feedback to the participant about the individually estimated nutrient intake. This probably increases the motivation for the participant to provide correct and complete data. A study in Ethiopia could show, the CIMI-Ethiopia reduced the data collection time by 25%

compared with the conventional 24 h-recalls (Bosha *et al,.* 2019a). Furthermore, research projects in Indonesia, Ghana and Ethiopia demonstrated, that the food group-based approach of CIMI produces valid results of macro- and micronutrient intake compared to NutriSurvey (Jati *et al,.* 2014, Bosha *et al,.* 2019a, Bosha *et al,.* 2019b, Wald *et al,.* 2019).

Therefore, this study aimed to validate the accuracy of the CIMI algorithm in comparison to NutriSurvey using socio-demographic and nutritional consumption data from a Tanzanian population (N= 1010 women). The data were gathered within the two research projects Scale-N and Trans-SEC in two different agro-ecological zones.

Methods

Study design

This study included data from two cross-sectional studies within the projects Trans-SEC (Innovating Strategies to safeguard Food Security using Technology and Knowledge Transfer) and Scale-N (Scaling Up Nutrition: Implementing Potentials of Nutrition-Sensitive and Diversified Agriculture to Increase Food Security). The Trans-SEC study was conducted from January to April 2015 and the Scale-N baseline study from July to August 2016. Data were collected from mothers or caregivers from eight different rural villages, four of them in each of the two districts Chamwino and Kilosa of the Dodoma and Morogoro region, respectively. The study population had a total of 1010 women, 344 from the Trans-SEC and 666 from the Scale-N study.

Socio-demographic, anthropometric and nutritional data were collected from all 1010 women. Body Mass Index (BMI) was calculated and classified according to the WHO categories (WHO 1995). The Scale-N study included additional data on serum vitamin A (retinol binding protein), iron status (serum ferritin, soluble transferrin receptor) and serum zinc, measured at the VitMin Lab (Dr. J.G. Erhardt, Willstaett, Germany) using ELISA and photometric methods as previously described (Erhardt *et al,.* 2004, Tetsuo *et al,.* 1982). Hemoglobin concentrations lower than 120 g/L were set as cut-off values for anemia (WHO 2001). Iron deficiency was defined as ferritin <12 µg/L and/or soluble transferrin receptor (sTfR) >8.5 mg/L (Cook et al,. 1992), while total body iron stores (IST) were calculated using SF and sTfR in an equation processed by Cook et al.: body iron (mg/kg BW) = - [log10(sTfR x 1000/SF) – 2.8229]/ 0.1207 (Cook *et al,.* 2003). Retinol <1.05 µmol/L was considered indicative of low vitamin A status (WHO 2001), while serum zinc <0.66 mg/L was used as cut-off for low/deficient zinc status (Hotz *et al,.* 2003).

Dietary assessment

Field surveys with questionnaires on maternal characteristics and dietary intake, including Dietary Diversity scores, FFQ and 24 h-recalls, were conducted. The 24 h-recalls were used for the in-depth evaluation of nutrient intake calculation by the CIMI algorithm, in comparison to NutriSurvey. Each woman was asked to recall all foods she had consumed during the day before the interview. Participants were requested to give quantities and ingredients of all foods consumed, during the whole day. Serving sizes were estimated and quantified using standardized plates, spoons and cups.

Nutrient intake calculation with the reference software NutriSurvey

NutriSurvey is a program that analyses the macro- and micronutrient content of individually consumed foods. When NutriSurvey is used, it is necessary to enter each individual food and the exact amount consumed in grams. Nutrient compositions of local foods and dishes were added from the 'Tanzania Food Composition Table' (Lukmanji et al,. 2008). The daily recommended nutrient intake values (RNI) for all micronutrients from the report 'Human Vitamin and Mineral Requirements' of a joint FAO/WHO expert consultation in Bangkok, were applied to assess the prevalence of insufficient micronutrient intake (WHO 2001). Due to the predominantly plant-based diet in the study area, RNI for low zinc absorption rates and 10 % iron bioavailability were applied (WHO 2001, De Carli et al,. 2018).

When foods were added from the 'Tanzania Food Composition Table', in which vitamin A contents were provided as retinol activity equivalents, they were converted to retinol equivalents (RE). In addition, micronutrient contents (RE, Fe, Zn, Ca, Mg) for the local leafy vegetable 'Mlenda' (Corchorus trilocularis in Kilosa and Ceratotheca sesamoides in Chamwino) were analysed by the Scale-N team in the laboratories of the University of Hohenheim (Gowele et al,. 2017).

Identification of food groups for CIMI

Contrary to NutriSurvey, CIMI evaluates the 24-hour recalls by grouping the individually consumed foods into food groups to reduce data entry. Consumed foods in the two districts were split into 23 different food groups according to the FFQ data of the Trans-SEC sub-sample. Composition of the food groups and contribution of individual foods to the different groups are shown in [Table 1].

Food items with high consumption levels, such as the main staple foods, usually form a separate group in contrast to other, less frequently consumed foods. Due to high preference for maize and bulrush millet in the study population, both food items were separated from other foods within the category “other cereals”. Furthermore, food items with high contents of particular nutrients were separated (e.g., vegetables were categorized into provitamin A-rich vegetables and other vegetables). The nutrient profiles of each food group were determined by calculating the average amount of nutrients with regard to the proportionate consumption of the food items in the target region that are aggregated in a specific food group. This was achieved using the following formula,

$$M_x = \frac{\sum_{k=1}^{n} c_k \cdot n_{xk}}{\sum_{k=1}^{n} c_k}$$

where M_x is the average content per gram of a nutrient x of a food group; c_k is the amount of an individual food item (grams) in the food group consumed, and n_{xk} is the content of nutrient x per gram of the individual food item k.

[Table 1]

Statistics

All statistical analyses were conducted with SPSS (Version 27). P values <0.05 were considered as statistically significant. Social demographic data and blood concentrations (hemoglobin, retinol, zinc and iron status) of the Scale-N women were presented by median (interquartile range), range (minimum – maximum), and percentage (number) for categorical and binary data; differences between districts were assessed using Mann-Whitney-U and Chi-Square tests, as appropriate.

The dietary intakes of macro- and micronutrients are given as means, medians and interquartile ranges; the comparisons between CIMI and NutriSurvey were assessed by differences in means, medians, bivariate correlation (Pearson) and Bland-Altman analysis (Bland-Altman plots).

Results

Socio-demographic characteristics for Trans-SEC and Scale-N women

A total of 1010 women of the Trans-SEC (N=334) and Scale-N (N=666) surveys, 479 from Chamwino and 531 from Kilosa district, were enrolled for the assessment of their nutritional status. Median age of all participating women was 37 years with a range between 19 and 85 years [Table 2]. The median weight and BMI were 53.4 kg and 22.3 kg/m2, respectively; both were higher in Kilosa compared to Chamwino. Women in Chamwino were significantly taller, but had a significantly lower BMI than those from Kilosa district. The overall higher proportion of women with overweight compared to underweight (27% vs. 6.8%) was observed, which was in particular evident in Kilosa (32% vs. 5.5%).

[Table 2]

[Figure 1]

Dietary intake of macro- and micronutrients assessed by CIMI-algorithm vs. NutriSurvey

The differences between the two methods were marginal for most of the nutrients: the difference was <15 % of the reference method's median for energy (1.8%), protein (4.0%), carbohydrates (2.2%), retinol equivalents (1.2%), folic acid (14,4%), vitamin B1 (10.0%), B2 (0.0%), B6 (0.0%), calcium (11.1%), iron (3.6%), and zinc (11.1%). However, calculation of fat and vitamin C by CIMI showed differences in median intake of 24.6% and 70.0%, respectively. Estimation of median nutrient intake was higher in CIMI for energy (26.8 kcal), fat (5.9 g), carbohydrates (5.4 g), retinol equivalents (5.1 µg), vitamin B1 (0.1 mg), vitamin C (13.9 mg) and iron (0.7 mg), whereas the calculated intake of protein (-1.4 g), folic acid (-46.5 µg), calcium (-43.8 mg) and zinc (-0.9 mg) was lower. Regarding vitamin B12, both methods identified a very low average intake (CIMI 0.7 µg, NutriSurvey 1.0 µg), as 70% of all women did not regularly consume animal products [Table 3].

[Table 3]

Bland-Altman Plots for energy, protein, iron and zinc were generated according to Giavarina et al. (Figure 1) (Giavarina 2015): The CIMI-algorithm and NutriSurvey provided comparable results, particularly at intakes below the recommended amounts. Overall, the calculations showed a negligible dispersion and were mostly within the defined confidence intervals (±1.96 SD), and thus did not contribute to a significantly different micronutrient intake assessment between the two methods.

Hemoglobin and serum micronutrients of the Scale-N women

Hemoglobin, iron status and serum retinol and zinc concentrations of women who participated in the Scale-N study are summarized in Table 4. There was an overall high prevalence of anemia (28%), iron deficiency (22%) and low serum zinc concentrations (22%) in the study population. In Kilosa, a significantly higher prevalence of anemia and iron deficiency was measured compared to Chamwino district, but a lower prevalence of low serum zinc.

[Table 4]

Association of micronutrient intake below the RNI with micronutrient deficiencies

The evaluation of CIMI and NutriSurvey with regard to the intake of vitamin A, iron and zinc below the recommended nutrient intake (RNI), and the subsequent diagnosis of anemia and further biomarkers of micronutrient deficiencies revealed congruent results for both methods. An intake of vitamin A and iron below the RNI was associated with a significantly higher prevalence of anemia and iron deficiency in both nutrient calculation methods. However, an intake of zinc below RNI was not directly related to lower serum zinc concentrations. The CIMI-algorithm identified slightly more women with a nutrient intake of vitamin A and zinc below the RNI who had anemia, low serum retinol, or low serum zinc compared to the NutriSurvey software [Table 5].

[Table 5]

Discussion

The overall aim of this study was to evaluate the accuracy of the new food group-based nutrient calculation algorithm CIMI compared to the reference software NutriSurvey with regards to the calculation of macro- and micronutrient intake. Data on dietary intakes (24 h-recalls) of 1010 women from the semi-arid rural Chamwino district and sub-humid rural Kilosa district were assessed, with a special focus on micronutrient intake below the recommended amount (Agency US 2008).

The accuracy of CIMI was high for energy, protein, carbohydrates and most micronutrients. On the one hand, simplification of nutrient intake assessment by categorizing single food items into specific food groups reduces data input, but on the other hand, the risk of deviation in nutrient calculation increases. This was more pronounced for nutrients with a high variation (e.g. vitamin A, vitamin C, folic acid and calcium) in foods belonging to one food group (e.g., 'green leafy vegetables', 'fish', 'pulses' or 'others fruits'), which showed less accuracy.

This phenomenon was also described by Jati et al., who investigated the food group-based approach in Indonesia (Jati et al,. 2014) and by Bosha et al. in Ethiopia (Bosha et al,. 2019b). In the present study, the results of CIMI-algorithm and NutriSurvey for energy, macronutrients and most of the micronutrients, were comparable with regard to the average intake. The lower correlation coefficient of vitamin A (0.512), 0.492 in Chamwino and 0.480 in Kilosa district, was due to the food groups' concept of CIMI. The food group 'green leafy vegetables' in CIMI calculates an average of all green leafy vegetables included in this food group e.g., Mlenda (*Corchorus trilocularis and Ceratotheca sesamoides*), Cowpea leaves and sweet potato leaves. While the leafy vegetable Mlenda or cowpea leaves, for instance, are very rich in provitamin A, other green leafy vegetables in the same group, such as cassava leaves or Chinese cabbage, do not contain high amounts of provitamin A. Women from Kilosa reported a high consumption of cowpea leaves, while women from Chamwino had a high intake of Mlenda (*Ceratotheca sesamoides*). The predetermined average of the provitamin A content in the 'green leafy vegetables' group leads to an underestimation of vitamin A intake compared to NutriSurvey, which only accounts for the actual consumed leafy vegetables. Similarly, the participants of Kilosa stated consuming ripe bananas and watermelon, but they hardly reported eating oranges. Nevertheless, the group 'fruits' in CIMI calculated an average of all fruits included in this food group. Oranges are vitamin C-rich fruits and contribute to 30% of the group's nutrient composition, which led to an overestimation of vitamin C intake by the CIMI-algorithm in regions where no, or only few oranges were consumed.

Although the CIMI results verged on the calculation of NutriSurvey for most of the micronutrients, some differences in the correlation coefficients occurred between both districts, particularly concerning vitamin C, calcium and iron. With regards to calcium, there was an underestimation of consumption in CIMI results compared to NutriSurvey, especially for the women from Chamwino, who mainly consumed the calcium-rich leafy vegetable Mlenda (*Ceratotheca sesamoides*). This underestimation, similar in the case of vitamin A, is due to the food groups concept of CIMI, which calculates the average of the calcium content of the 'green leafy vegetables group', which is clearly lower than the calcium content of Mlenda. Mlenda was the primarily and almost exclusively consumed green leafy vegetable in Chamwino, but rarely consumed in Kilosa, where multiple other vegetables with varying calcium and iron contents were consumed. The higher correlations in Chamwino with regard to calcium and iron can be explained by the little varied dietary habits of the women from this region, who consumed less food items than the more food diverse women from Kilosa. The low correlation regarding the calcium intake in Kilosa was primarily due to the consumption of sardines (small dried fish with eatable fish bone), which include extremely high amounts of calcium. Consumers of sardines were mainly located in Kilosa district. This led to statistical outliers showing very high calcium intake values in NutriSurvey and lower ones in CIMI, resulting in a weaker correlation for calcium. Nevertheless, the food group-based approach of CIMI is suitable to estimate nutrient intake at the population level.

In order to increase the accuracy on the individual level, further fragmentation of the food groups or optional deselection of not consumed foods within a food group would increase the precision of nutrient calculation. Such a CIMI already exists for Ethiopia, showing high validity, requires less time and is well accepted, by interviewers as well as for interviewed participants (Bosha *et al,*. 2019b, Bosha *et al,.* 2019a).

One of the advantages of CIMI is the fast and simple data input, since only the consumed amounts of the different food groups have to be entered. Results of nutrition analysis are available immediately after the interview, which enables the interviewer to inform participants about possible individual nutrient deficits and available food sources to close the gap [5]. In addition, individual feedback to the participants possibly increases the willingness to participate in such surveys and motivates the participants to provide correct answers.

Our study had some limitations: While the dietary patterns of the Tanzanian population vary greatly, only two agro-ecological zones in Tanzania where included. There are different main staples: maize is preferred in the West and South, millet in the middle and rice in the East. In addition, dietary assessment was only done in rural areas, where the meals are mainly prepared at home. Assessing nutrient intake in urban settings is much more challenging, due to the possibility to buy convenience food or eat out-of-home.

The nutrient intake calculation in our study was based on only one 24 h recall, which limits the quality of the results. According to Lombard et al., one 24 h-recall analysis is not sufficient to provide valid dietary intake results and more than three 24 h-recalls are required to obtain valid data (Lombard *et al,.* 2015). Furthermore, retrospective categorisation of 24 h-recall data into food groups might confound the results. Nevertheless, the CIMI-study in Ethiopia clearly demonstrated that the direct data input in CIMI during the interview, generated comparable results to NutriSurvey and showed a time saving for the interview of 25%, which did not take into account the time needed for classical 24 h-recall data analysis by nutrition software (Bosha *et al,.* 2019a).

As our findings have shown, CIMI calculation is prone to over- or underestimation of micronutrient intake due to fixed nutrient profiles for entire food groups. Therefore, identification of individual nutritional gaps by the CIMI-algorithm is less specific. Integration of an option enabling deselection of not-consumed foods in a food group might help to overcome this limitation. However, for rapid population-level assessment of nutrient intakes, the simple food group-based CIMI algorithm is appropriate and a useful tool for generating data needed to plan, implement, and measure the impact of intervention programs.

In conclusion, CIMI is a suitable tool for estimating nutrient intakes in rural Tanzania. Its application provides detailed information on energy, macro- and micronutrient intakes without requiring additional time for data analysis. Therefore, CIMI can be used in place of nutrient diversity assessment, which also does not provide quantitative data on intake of individual nutrients. Additional enhancements to CIMI, such as automatic calculation of percent compliance with nutrient intake recommendations and the ability for respondents to deselect foods within a food group, will further enhance usability.

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Disclosure of interest

The authors report there are no competing interests to declare.

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Table 1: Description of the food groups in CIMI-algorithm

	Food Group	**Contributing food items *(% contents of each food)***
1.	Maize	Maize flour dry (100%)
2.	Bulrush millet	Bulrush millet dry (100%)
3.	Sorghum	Sorghum flour dry (100%)
4.	Fried Bakery	Chapatti, African Donuts, Bhajia ->All three food items have an average contribution of 33.33%
5.	Other cereals	Rice (60%), finger millet (20%), wheat (20%)
6.	Plantain, white roots and tubers	Cooked bananas (30%), cassava (25%), white sweet potatoes (25%), potatoes (20%)
7.	Nuts	Groundnuts (90%), cashew nuts (10%)
8.	Pulses	Beans (kidney), cowpeas, pigeon peas, green grams, chicken peas, soya beans, Bambara nuts, lablab beans (hyacinths beans) ->All eight food items have an average contribution of 12.5%
9.	Vitamin A rich vegetables and yellow tubers	Yellow sweet potatoes (60%), pumpkin (25%), carrots (15%)
10.	Green leafy vegetables	Ilende [*Ceratotheca sesamoides*] (25%), cowpea leaves (20%), Mugunda [*Corchorus trilocularis*] (10%), amaranth (10%), sweet potato leaves (10%), Chinese cabbage (10%), cassava leaves (5%), spinach (5%), pumpkin leaves (5%)
11.	Other vegetables	Tomatoes (30%), onions (30%), African eggplant (30%), eggplant (5%), green pepper (5%)
12.	Meat	Beef (50%), chicken (15%), goat (15%), lamb (15%), pork (5%)
13.	Organ meat	Beef tripe (60%), beef liver (40%),
14.	Eggs	Chicken egg boiled (50%), chicken egg fried (50%)
15.	Milk and milk products	Yogurt (55%), cow's whole fat milk (40%), milk powder (5%)
16.	Fish (all types)	Sardines (40%), fish relish (30%), fried fish (20%), smoked fish (10%),
17.	Vitamin A rich fruits-A	Mangoes (50%), papaya (50%)
18.	Other fruits	Oranges (30%), watermelon (30%), ripe bananas (30%), pineapple (5%), avocado (5%)
19.	Red palm oil	Palm oil (100%)
20.	Other oils and fats	Coconut cream (60%), vegetable oil (40%)
21.	Added sugar/honey	Sugar (90%), honey (10%)
22.	Soft drinks	Carbonated drinks, Coca-Cola, fruit flavored drinks ->All three food items have an average contribution of 33.33%
23.	Beer/ local brews	Beer local grain (90%), beer commercial (5%), beer local-nonspecific (5%)

[CIMI: Calculator of Inadequate Micronutrient Intake]

Table 2: Socio-demographic characteristics of women who participated in Scale-N and Trans-SEC surveys.

	All	Chamwino	Kilosa	P
Women, N	**1010**	**479**	**531**	
Age [years][a]	37 (30, 45) 19 - 85	38 (30, 47) 20 -85	36 (30, 44) 19 - 81	0.029
Weight [kg][a]	53.4 (48.0, 60.5) 30.5 - 112.4	52.9 (48.0, 59.9) 30.5 - 99.0	53.8 (47.9, 61.6) 34.4 - 112.4	0.221
Height [cm][a]	154 (151, 158) 131 - 188	155 (152, 159) 136 - 188	154 (149, 157) 131 - 169	<0.001
BMI [kg/m^2][a]	22.3 (20.5, 25.2) 14.4 - 47.4	22.1 (20.2, 24.4) 14.4 - 40,0	22.7 (20.7, 26.1) 14.8 – 47.4	<0.001
BMI <18.5, % (n)[b]	6.8% (69)	8.4% (40)	5.5% (29)	
18.5<BMI<25, % (n)[b]	66% (667)	70% (334)	63% (333)	0.001
BMI ≥25, % (n)[b]	27% (274)	22% (105)	32% (169)	

Data are median (interquartile range), minimum-maximum[a] and percentage (number)[b]
P-values: Mann-Whitney U or Chi Square test as appropriate

Table 3: Comparison of means and medians of energy and nutrient intake calculated by CIMI and NutriSurvey (NS) in Chamwino and Kilosa district.

	N	CIMI			NS			CIMI - NutriSurvey			Pearson R
		Mean	Median	IQR	Mean	Median	IQR	Mean	Median	IQR	
Energy [kcal]	1010	1631	1574	1025, 2111	1565	1517	998, 1994	65.3	26.8	-49.1, 156.8	0.931
Chamwino	479	1230	1125	727, 1649	1230	1112	704, 1596	-0.4	9.8	-40.3, 56.5	0.936
Kilosa	531	1992	1904	1480, 2437	1868	1795	1415, 2288	124.5	92.3	-68.0, 296.8	0.903
Protein [g]	1010	40.1	34.5	21.7, 52.5	41.5	34.9	21.3, 54.3	-1.4	-1.4	-4.8, 3.6	0.898
Chamwino	479	27.5	23.9	14.8, 34.5	29.2	23.3	15.0, 35.5	-1.8	-1.5	-3.6, 0.4	0.887
Kilosa	531	51.5	45.4	32.9, 64.7	52.5	47.7	33.3, 65.0	-1.0	-0.7	-7.8, 7.0	0.876
Fat [g]	1010	44.4	32.5	16.4, 62.7	30.2	24.0	13.4, 39.6	14.1	5.9	0.5, 23.0	0.778
Chamwino	479	24.4	18.0	9.5, 30.5	21.6	15.8	9.2, 27.2	2.8	1.6	-1.3, 5.6	0.869
Kilosa	531	62.3	55.9	33.1, 81.1	38.0	33.4	21.7, 47.2	24.3	18.0	5, 38.5	0.707
Carbohydrates [g]	1010	257.6	247.1	149.3, 342.8	261.3	241.9	147.7, 353.9	-3.6	5.4	-24.2, 17.1	0.929
Chamwino	479	178.2	161.2	99.8, 231.6	173.8	149.1	94.7, 229.3	4.4	10.5	1.6, 18.1	0.891
Kilosa	531	329.3	316.8	245.7, 404.5	340.2	325.5	251.5, 417.6	-10.9	-12.8	-40.5, 16.6	0.899
RE [µg]	1010	515	384	115, 717	685	422	135, 904	-170	5.1	-342.1, 89.1	0.512
Chamwino	479	639	515	319, 782	894	663	343, 1196	-254	-7.5	-503.1, 90.5	0.492
Kilosa	531	402	195	70, 573	496	200	47, 562	-94.1	9.1	-100.9, 83.7	0.480
Vitamin B1 [mg]	1010	1.2	1.2	0.8, 1.6	1.1	1.0	0.6, 1.4	0.1	0.1	0, 0.3	0.832
Chamwino	479	1.1	1.0	0.8, 1.5	1.0	0.9	0.5, 1.3	0.1	0.1	0, 0.3	0.853
Kilosa	531	1.3	1.2	0.9, 1.6	1.1	1.1	0.7, 1.5	0.2	0.2	0, 0.3	0.808
Vitamin B2 [mg]	1010	1.1	1.0	0.6, 1.4	1.1	1.0	0.6, 1.5	0	0	-0.2, 0.1	0.768
Chamwino	479	1.1	1.0	0.7, 1.5	1.2	1.0	0.7, 1.5	-0.1	0	-0.1, 0.1	0.738
Kilosa	531	1.0	0.9	0.6, 1.4	1.1	0.9	0.6, 1.5	0	0	-0.3, 0.2	0.805

Table 3 continued

	N	CIMI			NS			CIMI - NutriSurvey			Pearson R
		Mean	Median	IQR	Mean	Median	IQR	Mean	Median	IQR	
Vitamin B6 [mg]	1010	1.5	1.4	1.0, 2.0	1.5	1.4	0.9, 1.9	0	0	-0.2, 0.3	0.810
Chamwino	479	1.4	1.2	0.9, 1.8	1.4	1.1	0.8, 1.7	0	0.1	-0.2, 0.3	0.766
Kilosa	531	1.7	1.6	1.1, 2.0	1.7	1.5	1.1, 2.1	0	0	-0.1, 0.3	0.844
Folic acid [µg]	1010	289	255	176, 379	373	324	215, 481	-84.8	-46.5	-132.5, -7.1	0.773
Chamwino	479	251	217	159, 323	341	284	197, 449	-90.1	-50.5	-119.8, -17.4	0.778
Kilosa	531	322	303	202, 416	402	356	244, 534	-80.0	-45.1	-143.0, 11.7	0.775
Vitamin B12 [µg]	1010	0.7	0	0, 0	1.0	0	0, 0.4	-2.7	0	0, 0	0.715
Chamwino	479	0.3	0	0, 0	0.3	0	0, 0	0	0	0,0	0.705
Kilosa	531	1.1	0	0, 1.6	1.5	0	0, 1.8	-0.5	0	-0.3, 0	0.719
Vitamin C [mg]	1010	45.7	33.1	17.8, 61.5	39.5	19.9	4.2, 52.1	6.1	13.9	-4.4, 29.8	0.534
Chamwino	479	32.0	27.1	15.3, 42.4	33.4	9.2	1.5, 44.6	-1.4	12.4	-16.9, 26.9	0.318
Kilosa	531	58.0	47.1	26.0, 78.1	45.1	29.9	11.9, 55.9	12.9	16.4	-1.5, 34.7	0.685
Calcium [mg]	1010	434	369	237, 542	570	394	196, 749	-136	-43.8	-240.2, 113.4	0.534
Chamwino	479	517	459	309, 622	740	608	380, 945	-222.9	-163.7	-350.2, -22.8	0.771
Kilosa	531	360	300	188, 461	417	221	135, 439	-57.5	55.1	-83.6, 207.0	0.212
Iron [mg]	1010	25.2	21.8	14.1, 32.7	23.7	19.2	12.6, 29.0	1.5	0.7	-2.0, 5.8	0.775
Chamwino	479	31.9	29.0	20.0, 39.9	31.9	28.2	19.5, 43.0	0	0	-2.6, 3.8	0.872
Kilosa	531	19.1	16.7	10.9, 24.3	16.3	14.2	10.2, 19.8	2.8	2.0	-1.5, 7.7	0.428
Zinc [mg]	1010	9.1	7.1	5.3, 9.9	7.8	8.1	5.9, 11.3	-1.2	-0.9	-2.1, 0	0.838
Chamwino	479	8.4	7.6	5.3, 10.9	9.5	8.2	5.8, 12.2	-1.1	-0.9	-1.8, -0.3	0.895
Kilosa	531	7.3	6.9	5.2, 9.1	8.7	8.0	6.0, 10.7	-1.4	-1.0	-2.5, 0.2	0.745

N= Number, IQR= Interquartile range, RE = retinol equivalents; Pearson correlation: all p-values were <0.001

Table 4: Hemoglobin, iron status (iron stores, serum ferritin and soluble transferrin receptor) and serum retinol and zinc of the women who participated in the Scale-N survey

	All	Chamwino	Kilosa	P
Women, N	**666**	**333**	**333**	
Hb [g/L][a]	127 (118, 135)	131 (123, 139)	124 (113, 131)	<0.001
Hb <120g/L, % (n)[b]	28 (187)	17 (56)	39 (131)	<0.001
Retinol [µmol/L][a]	1.3 (1.6, 2.0)	1.7 (1.3, 2.0)	1.3 (1.1, 1.6)	<0.001
Retinol <1.05, % (n)[b]	7 (48)	6 (21)	8 (27)	0.369
Iron stores [mg/kg BW][a]	5.7 (3.9, 7.8)	6.3 (4.4, 8.2)	5.4 (3.0, 7.1)	<0.001
Iron stores <0, % (n)[b]	7 (48)	5 (18)	9 (30)	0.072
SF <12 or sTfR >8.5[b]	22 (147)	16 (54)	28 (93)	<0.001
Zinc [mg/L][a]	0.75 (0.68, 0.84)	0.73 (0.67, 0.82)	0.78 (0.70, 0.85)	0.001
Zn <0.66 mg/L, % (n)[b]	20 (132)	25 (82)	15 (50)	0.002

Hb: Hemoglobin, SF: serum ferritin, sTfR: soluble transferrin receptor, Zn: zinc
Data are median (interquartile range)[a] and percentage (number)[b]
P-values: Mann-Whitney U and Chi Square test, as appropriate.

Anemia is defined as Hb <120g/L, low retinol as retinol <1.05 µmol/L, negative iron stores as iron stores <0 mg/kg BW, iron deficiency as SF <12 µg/L and/ or sTfR >8.5 mg/L and low zinc status as Zn <0.66 mg/L

Table 5: Prevalence of anemia and vitamin A, iron and zinc micronutrient deficiencies in the Scale-N women depending on nutrient intake (vs. < and ≥ RNI) calculated by CIMI-algorithm and NutriSurvey

	RE intake < RNI		**RE intake ≥ RNI**	
Women % (n)	CIMI n=412	NS n=357	CIMI n=254	NS n= 309
Anemia	31(126)**	29 (105)*	19 (47)	22 (68)
Retinol <1.05 µmol/L	**8 (34)**	**7 (26)**	**6 (14)**	**7 (22)**
SF<12 and/or sTfR>8.5	26 (106)*	26 (93)*	16 (41)	18 (54)
Zinc <0.66 mg/L	20 (81)	19 (68)	20 (51)	21 (64)
	iron intake < RNI		**iron intake ≥ RNI**	
	CIMI n=493	NS n=522	CIMI n=173	NS n=144
Anemia	**29 (145)****	**29 (150)***	**16 (28)**	**16 (23)**
Retinol <1.05 µmol/L	8 (40)	8 (39)	5 (8)	6 (9)
SF<12 and/or sTfR>8.5	**25 (121)***	**24 (124)***	**15 (126)**	**16 (23)**
Zinc <0.66 mg/L	19 (91)	19 (101)	24 (41)	22 (31)
	zinc intake < RNI		**zinc intake ≥ RNI**	
	CIMI n=554	NS n=499	CIMI n=112	NS n=167
Anemia	27 (151)	26 (129)	20 (22)	26 (44)
Retinol <1.05 µmol/L	8 (43)	7 (34)	5 (5)	8 (14)
SF<12 and/or sTfR>8.5	23 (127)	24 (118)	18 (20)	17 (29)
Zinc <0.66 mg/L	**20 (113)**	**21 (104)**	**17 (19)**	**17 (28)**

All data are presented in percentages and numbers in brackets,
P-values (Chi-square test): *<0.05, **<0.001
Anemia is defined as Hb <120g/L, low retinol as retinol <1.05 µmol/L, iron deficiency as SF <12 µg/L and/or sTfR >8.5 mg/L and low zinc status as zinc <0.66 mg/L
RNI: recommended nutrient intake: RE 500 µg/d, iron 29 mg/d (10% bioavailability), zinc 9.8 mg/d (low bioavailability) (De Carli *et al,*. 2018)

Figure 1:

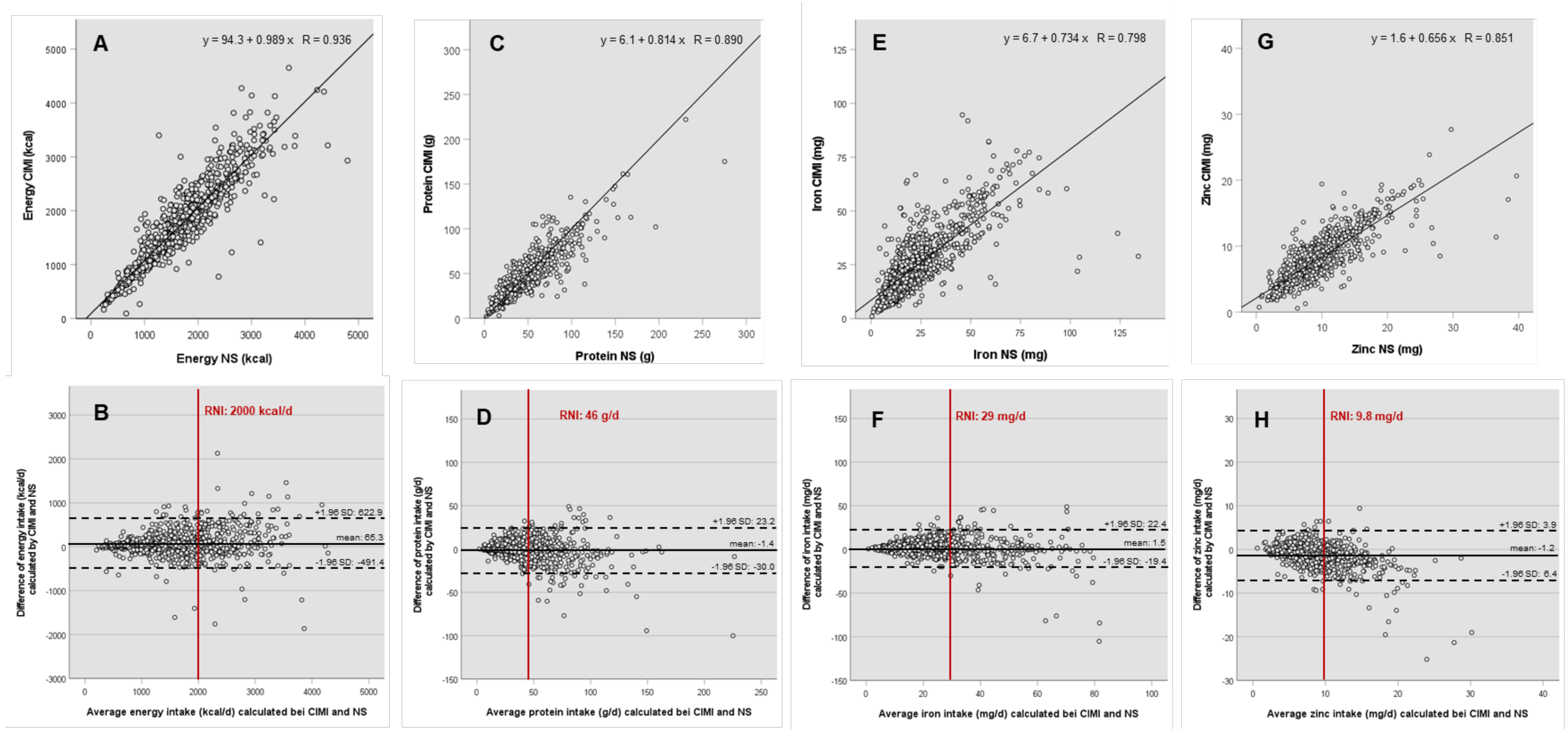
A
y = 94.3 + 0.989 x R = 0.936
Energy CIMI (kcal)
Energy NS (kcal)
C
y = 6.1 + 0.814 x R = 0.890
Protein CIMI (g)
Protein NS (g)
E
y = 6.7 + 0.734 x R = 0.798
Iron CIMI (mg)
Iron NS (mg)
G
y = 1.6 + 0.656 x R = 0.851
Zinc CIMI (mg)
Zinc NS (mg)
B
RNI: 2000 kcal/d
+1.96 SD: 622.9
mean: 65.3
-1.96 SD: -491.4
Difference of energy intake (kcal/d) calculated by CIMI and NS
Average energy intake (kcal/d) calculated bei CIMI and NS
D
RNI: 46 g/d
+1.96 SD: 23.2
mean: -1.4
-1.96 SD: -30.0
Difference of protein intake (g/d) calculated by CIMI and NS
Average protein intake (g/d) calculated bei CIMI and NS
F
RNI: 29 mg/d
+1.96 SD: 22.4
mean: 1.5
-1.96 SD: -19.4
Difference of iron intake (mg/d) calculated by CIMI and NS
Average iron intake (mg/d) calculated bei CIMI and NS
H
RNI: 9.8 mg/d
+1.96 SD: 3.9
mean: -1.2
-1.96 SD: 6.4
Difference of zinc intake (mg/d) calculated by CIMI and NS
Average zinc intake (mg/d) calculated bei CIMI and NS

Figure captions

Figure 1:
Scatter plots (upper row) and Bland-Altman plots (lower row) of energy (A,B), protein (C,D), iron (E,F) and zinc (G,H) intake calculated by CIMI and NutriSurvey. Scatter plots include predictive equations, vertical lines (red) in the Bland-Altman plots represent the recommended nutrient intake values (RNI)

4 Discussion

The overall aim of this doctoral project was to assess the anthropometrics and hemoglobin status in relation to the dietary intake and frequency of consumed food items by season of female and male pigeon pea farmers in Tanzania and Mozambique. The analyses focused on common problems of malnutrition namely anemia, underweight, overweight and consumption deficiencies of micronutrients e.g., iron, zinc and vitamin A. MUAC as an alternative anthropometric measurement tool to the BMI was evaluated in rural settings, and the food-group based CIMI algorithm was tested for Tanzania in comparison to 24-hour recalls entered into NutriSurvey. The impact of seasonality on dietary habits and nutritional status of the enrolled farmers was investigated, focusing on the differences between rainy and dry seasons to understand the consequences on "food security" in the study regions.

4.1 Triple burden of malnutrition in Sub-Sahara Africa

Overall, 1526 female (55.7%) and male (44.3%) farmers participated in the baseline study of Vegi-Leg, of which 669 were based in Lindi (Tanzania) and 857 in Gurué (Mozambique). The Vegi-Leg study confirmed the trend of a coexistence of a triple burden of anemia, underweight and overweight in rural households of Tanzania and Mozambique. According to the Tanzanian demographic and health survey from 2015-2016, 49% of the women aged 15-49 in Lindi had anemia, 7% were underweight and 28% were overweight [84]. The demographic and health survey from 2011 of Mozambique stated that 62% of the women from Zambézia (15-49 years) had anemia , while 14% were underweight and 6% were overweight [70]. Although, studies from rural SSA reveal a higher prevalence of underweight and lower prevalence of overweight and anemia compared to urban areas, the shift towards a TBM and a coexistence of undernutrition, overweight and anemia in rural households in SSA are on the rise [9].

This was previously stated in a study involving 23 countries across SSA and conducting Demographic and Health Surveys between 2008 and 2017 [8]. A former study from 2003 revealed high numbers of overweight mothers with increasing numbers in rural areas in Africa, claiming the increase to general economic development, not urbanization [85]. Anthropometric measurements from 210 women from 3 rural districts of northeastern and central Tanzania were assessed in 3 different seasons showing a 22% prevalence of overweight compared to 25% overweight in urban Morogoro, showing that overweight is not restricted solely to urban areas [86,87]. Another recent study from 2021 revealed an emerging prevalence of overall overweight and abdominal obesity amongst adolescents (43% in girls and 21% in boys) in rural high schools in South Africa, due to an energy-dense and nutrient-poor diet mainly based on starches [88]. In agreement, a previous study from Uganda examining 683 young female and male adults did not observe significant rural-urban differences in the prevalence of overweight, which was 10.6% and 10.2% respectively [89]. The findings of a study from Malawi on 15013 adults living in rural, as well as urban areas confirmed the constant disappearance of any urban-rural gap in the prevalence of overweight and related diseases such as hypertension and type 2 diabetes [90].

Thus, overweight is a public health concern in Sub-Saharan Africa, associated with an increased risk of metabolic syndrome with rising levels of cardiovascular diseases (CVDs) and type 2 diabetes according to a recent meta-analysis from 2020 comprising 65 studies with over >34.000 healthy adults [91]. In this systemic review, the prevalence of metabolic syndrome was generally higher in women than in men, with highest incidence in Southern Africa, followed by Eastern Africa. Rapid changes in nutritional habits and reduced physical activity have resulted in an increasing prevalence of overweight among developing countries, such as those in Sub-Saharan Africa [92]. This transition can be attributed to the diet shifts towards an increased dependence on energy-densed foods, away-from-home food consumption, and increased intake of refined carbohydrates, oils and sugar-sweetened beverages, as observed in the present study. According to the 24-hour recalls of the female and male farmers of both countries, their main meal consisted of cereals in form of polished rice or maize. There was a significantly higher consumption prevalence of cereals (88%), and sugar-sweetened beverages (30%), compared to fruits (10%) and vegetables (21%). The anthropometric measurements (BMI and MUAC) of the present study population revealed a significantly higher prevalence of overweight and obesity in women than in men. In Tanzania, one in three women was overweight and one in ten was obese. Underweight only played a role among men in both countries, as the prevalence of underweight was higher than the prevalence of overweight (13.6% vs. 8.1% in Tanzania and 17.1% vs. 4.6% in Mozambique). In Lindi, positive correlations were measured between the BMI and the weekly consumption of ‘bread and similar products’ (R_1=0.083, R_2=0.177) and ‘sugar’ (R_1=0.164, R_2=0.147), and the FFQ showed that in both seasons overweight farmers consumed significantly more frequently ‘bread and similar products’, ‘sugar and sweets’, and ‘tea, coffee and alcoholic beverages’ than farmers with under- or normal weight., which could be an explanation for the high prevalence of overweight in Lindi. On the contrary, the consumption of 'legumes and pulses' was inversely correlated with BMI signifying that underweight and normal weight farmers consumed legumes (e.g., pigeon peas) more frequently than pre-obese/ obese farmers, which was in accordance with the findings of a previous study from 2014 showing that the consumption of legumes is advantageous and especially relevant to the management of obesity [93].

A systematic analysis of multiple epidemiological studies and health surveys between 1980 and 2008 examined data of 199 countries and 9.1 million participants and estimated worldwide rising trends of the mean BMI by 0.4 kg/m^2 per decade for men and 0.5 kg/m^2 per decade for women [94]. Another review analysing sociodemographic, anthropometric and dietary intake data between 1980 to 2009, described an overall significant increase in overweight in nearly all Sub-Saharan African countries [1]. Their findings revealed socioeconomic status, female sex, age, parity, physical inactivity, and increased energy, fat, and sugar intake as powerful predictors of overweight. Even though women are commonly the study target of nutritional assessments in Sub-Sahara Africa, as they are culturally responsible for food preparation and feeding processes of children, the Vegi-Leg project also studied male farmers for a better understanding of overall dietary habits in the study villages. In both study regions of Vegi-Leg the prevalence of overweight was 4 and 3 times higher in women than in men, respectively (35% vs. 8% in Tanzania, and 16% vs. 5% in Mozambique). A study from South Africa among 1559 adolescents revealed a positive correlation between being female, or black African and being overweight [95].

In total, 35% of the farmers studied in Vegi-Leg were anemic. In both study regions, an overall higher prevalence of anemia in Mozambique than in Tanzania, and in both study regions a significantly higher anemia prevalence in women than in men was detected: each second woman in Mozambique and each third woman in Tanzania was anemic. One reason for a higher prevalence of anemia in women compared to men is likely their higher demand of iron, during menstrual bleeding, pregnancy, lactation, and iron deficiency during their reproductive cycle [96]. Anemia in women of reproductive age is a major public health challenge for low- and middle-income countries with long-term negative effects on their health and the health of their children, such as cognitive impairment, decreased immunity, miscarriage, and low birth weight [29,97,98].

Based on the findings of a review from 2011 studying the global prevalence and major causes of anemia, most cases of anemia are due to iron deficiency, which often occur simultaneously with folate deficiency and/or vitamin B12 deficiency, as well as with infections [99].

The present study revealed, that a higher consumption of food groups like ‘fruits’ 'vegetables', and ‘other vegetables’ was associated with a lower prevalence of anemia. In Lindi, the consumption frequency of the food groups ‘flesh meat and organ meat’, ‘fish and seafood’, ‘other vegetables’, ‘oil and fat’ and ‘bread and similar products’ correlated positively with the hemoglobin status in both seasons. Fish and meat represent excellent sources for iron, and anemia is mainly connected to dietary iron deficiency [96]. Although the farmers in the Vegi-Leg study never consumed meat and rarely consumed fish (< once a week) , non-anemic farmers consumed fish more often (2 vs. 1) than anemic farmers according to the FFQ. Tata et al. exposed in his survey in Cameroon using 24-hours-recalls, that women which consumed significantly more vitamin A rich fruits, vegetables and animal sourced foods were less affected from moderate and severe anemia than other women of the study population who did not or consumed small amounts of these food items (63% vs. 73%) [100]. In agreement, a former review including data from 38 countries and assessing trends in anemia among WRA between 1990 and 2007, confirmed that adequate dietary diversity, and specifically the consumption of iron-rich foods was a vital determinant of the micronutrient status of both women and their children [101].

4.2 Association of micronutrient nutrition with underweight, overweight and anemia by season

The Vegi-Leg project aimed to reduce the influence of seasons on farmers' diets by increasing the durability of pigeon peas and local dark green leafy vegetables with improved post-harvest processing methods. In Lindi, the follow-up survey took place during the rainy season (March) with 580 participants (87% of the baseline study population). By comparing baseline and follow-up data, the influence of seasonal variations was investigated, showing in both study regions a significant decrease in the consumption of ‘legumes & pulses’ and a significant increase in the consumption of ‘green leafy vegetables’ during the rainy season. During the rainy season, the consumption of ‘pumpkin leaves’ in Tanzania and ‘Amaranth leaves’ in Mozambique increased significantly, likely due to increased availability. In agreement, Hudelson et al observed that adequate consumption of vitamin A rich foods in rural Ghana is hindered by seasonality as green leafy vegetables are abundant only in the rainy season [102]. Another study from 2010/2011 analysed 228 school-aged children from rural Ghana during different seasons, and found that compared to the dry season, more children consumed vitamin A-rich dark green leafy vegetables (52.6% vs. 23.3%) and vitamin A-rich fruits (64.0% vs. 0.9%) in the rainy season [103]. Recent studies from Burkina Faso and from Nigeria likewise stated that green leafy vegetable and fruit consumption was higher in the rainy season compared to the dry season [104,105].

In the present study, ‘fruits’ were consumed significantly more frequently in Mozambique during the rainy season (+40.7%), while in Tanzania their consumption decreased by 26%. The increased availability of mangoes and decreased availability of oranges during the rainy season in Mozambique and Tanzania, respectively, were the main contributing factors according to the FFQs of both seasons. Foods and food groups that are affected by high seasonal variations have the potential to lead to seasonal deficiencies of micro- and macronutrients. By detecting these specific foods, it is possible to develop strategies to reduce the influence of seasons and improve the nutritional situation in rural Tanzania and Mozambique.

A former review of 23 studies from developing countries in Sub-Saharan Africa and Asia, showed a strong relationship between anemia in women and seasonality, where anemia increased during rainy season due to food shortage, higher prices of healthy foods (e.g., fruits and vegetables), and higher malaria transmission compared to dry season [106,107]. Additionally, they found a 13% higher prevalence of mothers with underweight (BMI<18.5 kg/m^2) in the pre-harvest season compared to the postharvest season.

According to the HDDS of Tanzania and Mozambique all food groups were consumed less frequently during the rainy season, with the exception of 'green leafy vegetables' in both countries, 'cereals' in Tanzania, and 'fruits' in Mozambique.

'Green leafy vegetables', 'fruits' and 'other vegetables' provide important micronutrients like provitamin A, iron and zinc, while 'legumes and pulses' (e.g., pigeon peas) are an excellent source for proteins. 100 g of pigeon peas contain, depending on the variety, up to 21.7 g protein and 4.7 mg iron [108]. Pigeon peas collected from the Vegi-Leg study area in Tanzania revealed an excellent amino acid profile with 18 amino acids and a (median) total of 19 gram/100 grams [109].

Due to the low consumption of animal-based proteins (e.g., meat or fish) in the respective study sites (less than once a week according to FFQ), legumes and pulses are considered essential for a sufficient protein and iron intake. In sub-Saharan Africa, the average consumption of meat is only at 11 kg per person per year and is hence less than a third of the global average [110]. According to the FAO data from 2016-2018, the average consumption of meat was only 6.8 kg per year in Tanzania and 7.2 kg per year in Mozambique, which is lower than the average in total sub-Saharan Africa [111]. Consequently, a sufficient consumption of legumes and pulses has the potential to reduce the prevalence of protein malnutrition in sub-Saharan Africa [112]. However, in Lindi the consumption frequency of pigeon peas decreased significantly from the baseline survey in August to the follow up in March. The contribution of legumes and pulses to the total protein intake in sub-Saharan Africa is higher than in any other region in the world. In 2016, the yearly consumption of pulses per capita was 22 kg for East Africa, and therefore three times higher than the global average [110].

According to a previous Vegi-Leg study from 2020 on 303 farming households in Lindi, the mean intake of pigeon peas in the harvest season of 80g/person/day, decreased to 18g/person/day during the lean season, which is less than the FAO recommendations [113]. These significant decreases in the consumption of pigeon peas were also observable within the evaluation of the FFQ from Tanzania (5 vs. 0) and Mozambique (4 vs.2) between dry and rainy season.

The inadequate consumption of micronutrient-dense and protein-rich foods such as green leafy vegetables, legumes and meat is an important contributing cause for anemia and deficiencies of vitamin A and iron in the present study regions. According to the 24-hour recalls of the farmers of the baseline study, only every fifth person in Tanzania and every second person in Mozambique reported consuming 'green leafy vegetables', whereas only 1 in 10 farmers reported consuming meat. Overall, a small proportion of female and male farmers reached the recommended daily dietary intake of vitamin A (10%), iron (51%) and zinc (44%). Legumes in Tanzania and starchy plants in Mozambique were the dominant sources of vitamin A, while cereals covered over half of the iron and the zinc intake in both countries.

In Lindi, the consumption frequency of maize, sugar and sweetened tea was significantly higher than in Gurué, which is likely contributing to the higher overweight prevalence in Tanzania. A high consumption of staple foods can help meet the energy requirements, but may lead to lower intakes of animal products and food items rich in iron, vitamin A and zinc and consequently to protein malnutrition and micronutrient deficiencies [114]. Monotonous diets are known to be particularly problematic in low-income countries, where cheap and filling starchy staple foods dominate, and the range of nutrient-dense foods such as fruits, vegetables, and animal-source foods is limited in availability and affordability [41].

The prevalence of anemia in Lindi increased significantly from 27% in August to 34% in the follow-up study in March. The evaluation of the FFQ between the seasons revealed, except for a significant increase from1 to 2 times per week of fish consumption in the rainy season, no difference in the very low weekly consumption of animal-based food groups (median = 0 for meat, eggs and milk products in both seasons). However, the consumption of 'legumes and pulses' e.g., pigeon peas decreased significantly in the follow-up study (7 vs. 2 times per week). Therefore, the increased prevalence of anemia in the follow-up survey in Lindi might have been due to the decreased consumption frequency of 'legumes and pulses', i.e., the decreased dietary iron intake. Vitamin A, including pro-vitamin A in fruits and vegetables, e.g., β-carotene in mangos or β-cryptoxanthin in oranges can prevent anemia, by enhancing the growth and differentiation of erythrocyte progenitor cells and mobilizing iron stores from tissues [115]. Farmers in Lindi consumed significantly less frequently 'other vegetables' and 'fruits' during the follow-up survey, which could be due to the declined pro-vitamin A consumption an additional contributor to the higher anemia prevalence in the rainy season.

Another explanation for the higher prevalence of anemia during the rainy season are persistent infectious diseases such as cholera and malaria, which are increasingly prevalent within higher rainfall compared to the dry season [116,117]. Malaria-induced anemia involves increased removal of circulating infected and uninfected erythrocytes, and a decreased production of erythrocytes in the bone marrow [118]. Thus, in addition to a poorer supply of micronutrients due to seasonal variations of food availability, infectious diseases such as malaria may have contributed to the higher prevalence of anemia during the rainy season.

4.3 Mid-upper arm circumference as an alternative marker to detect malnutrition

The present study revealed that MUAC correlates strongly and positively with the BMI and its defined categories and is therefore capable of detecting underweight, as well as overweight in adults and adolescents. Especially in rural settings, BMI can be impractical due to the necessary scales and stadiometers for weight and height measurements, whereas the needed tape for MUAC measurements is a less resource-intensive measure for community-based screening of malnutrition [119]. A previous study using data from 2421 men and 3248 women from 8 countries (Mali, India, Senegal, Zimbabwe, Somalia, Ethiopia, Papua New Guinea and China) confirmed in agreement with the present study, that MUAC could be used for the simple screening of nutritional status, when rapid screening of an adult population is required [120]. In order, to determine suitable MUAC cut-offs for different forms of malnutrition, the present analysis identified for underweight 55% and 78% of underweight farmers with a MUAC<24cm calculated via multiple regression analysis, and <25cm via highest Youden's index, respectively. Further, this study was one of the first to calculate and suggest MUAC cutoffs for overweight: MUAC ≥30.5cm calculated via linear regression detected 74%, whereas MUAC ≥29cm calculated via highest Youden's index detected 90% of overweight farmers.

In the present study the positive correlations between BMI and MUAC were stronger in Tanzania than in Mozambique, and in female than in male farmers. A former study among 154 (92 female and 62 male) young adolescents in Tanzania indicated that BMI and MUAC measurements showed a positive correlation for both sexes, though in agreement with our findings, the relationship between BMI and MUAC was stronger among adolescent females ($R = 0.846$) compared to adolescent males ($R = 0.459$), especially who were overweight or obese [121]. They claimed to be the first to compare the BMI and MUAC relationships described by sex and to show that the correlation between BMI and MUAC is weaker in males then in females. According to their findings the weaker correlation in males can be due to the higher male stunting rates or due to different body proportions and fat distribution between females and males, where males gain more muscle mass in the upper body and females gain more fat mass in hips and thighs during puberty. Another meta-analysis from 2020 assessed a global mid-upper arm circumference cut-off to assess underweight in adults using data of a total sample size of 13 835 adults from 20 datasets including countries in Africa. They found that sensitivity (SENS) was higher and specificity (SPEC) lower in females compared to their male counterparts, similarly indicating a higher correlation of BMI with MUAC in females [122].

Anthropometric data of farmers ≥65 years of age of the present study, were separated from the rest and tested with the suggested cut-offs for both underweight and overweight. More old people were scanned with the calculated MUAC cutoffs for underweight than with that for overweight, suggesting lower MUAC cut-offs for the elderly. A former study among older female and male participants (n = 1307 ≥ 65 years) revealed a reduction of MUAC within a three years period, irrespective of changes in body weight, which was explained by muscular atrophy and bone loss in older age, proposing choosing lower cut-off points to assess malnutrition in subjects ≥65 years [123]. MUAC with adjusted cut-offs for older people, appears to be an appropriate marker for assessing poor nutritional status, especially when accompanied by muscular atrophy, bone loss, kyphosis or adults with edema due to protein-energy malnutrition [124]. As stated by a previous study from 2017 among elderly from rural India, MUAC is easy to measure and is highly correlating with BMI, thus can be used routinely in rural settings to immediately assess undernutrition in elderly [125]. In addition, previous studies have clearly shown significant ethnic differences in regional adiposity and body composition measures at the same level of BMI [126,127]. Therefore, the consideration of sex, age and ethnicity-specific cutoffs for BMI, as well as MUAC would be useful to tailor intervention strategies against different forms of malnutrition. The advantages of the BMI as cheap, quick, and easy to use measurement tool of different forms of malnutrition are also granted in MUAC with additional advantages of being even faster, less elaborate and suitable for pregnant women and weight influencing health related issues e.g., edema, amputation, wheelchair. Nevertheless, compared to scales and stadiometers, accurate MUAC measurements require highly trained personnel to avoid biased measuremets.

4.4 The food-group based algorithm (CIMI) for assessing dietary nutrient intake

The evaluation of the food group-based nutrient calculation algorithm CIMI in comparison to the reference software Nutrisurvey showed high accuracy of CIMI for calculating the dietary intake of macronutrients (energy, protein, carbohydrates) and most micronutrients. There were differences with regard to micronutrients with a high variation (e.g., vitamin A, vitamin C and calcium) in foods belonging to one food group (e.g., green leafy vegetables and others fruits), which was in line with the results observed in the comparable validation studies conducted in Ethiopia, Indonesia and Ghana [66-69]. The predetermined average of the nutrients content in the respective food groups leads to an under- or overestimation of specific micronutrients compared to NutriSurvey, that only accounts the actual consumed food item.

For instance, the food group ‘green leafy vegetables’ in CIMI calculates an average of all green leafy vegetables included in this food group e.g., Mlenda (Corchorus trilocularis and Ceratotheca sesamoides), Cowpea leaves and sweet potato leaves. While the leafy vegetable Mlenda or cowpea leaves, are very rich in provitamin A, other green leafy vegetables in the same group, such as cassava leaves or Chinese cabbage, do not contain high amounts of provitamin A. The predetermined average of the provitamin A content in the ‘green leafy vegetables’ group leads to an underestimation of vitamin A intake compared to NutriSurvey, which only calculates the actual consumed leafy vegetables. Similarly, oranges are vitamin C-rich fruits and contribute to 30% of the group’s nutrient composition, but were not consumed as frequently as watermelon or bananas in the present study, which led to an overestimation of vitamin C intake by the CIMI-algorithm in regions where no, or only few oranges were consumed.

The present study generally illustrates that CIMI validly calculates the energy and most macro- and micronutrients intake in rural Tanzania and identifies the inadequacy of micronutrient intake of individuals using the cutoff points of RNI of FAO/WHO. Unlike other dietary assessment techniques, CIMI provides results immediately after an interview is completed, which enables the enumerator to provide direct feedback to the interviewee and suggest dietary behaviour improvements.

CIMI performed comparably with NutriSurvey in capturing dietary intake and nutrient adequacy outcomes in rural settings. Given limited data on CIMI outcomes and the cross-sectional study design, prospective studies are warranted to assess CIMI performance in capturing malnutrition outcomes.

4.5 Strengths and limitations

The present study has several strengths mainly derived from its large sample size, inclusion of data of female, as well as male participants and data from three different projects conducted in comparable rural villages of the two neighboring East-African countries, Tanzania and Mozambique. The large sample size provided more accurate mean values, which allowed the accurate assessment of the nutritional status of the enrolled farmers. The Vegi-Leg study is one of the first studies to include not only female, but also male farmers from rural Tanzania and Mozambique in anthropometric, hemoglobin and dietary assessments, allowing a better understanding and overall picture of their nutritional status. Further, the MUAC cutoffs proposed in the present study present one of the first cut-off suggestions to detect overweight in addition to underweight in an adult study population.

The present study also had limitations, such as under-reporting of portion sizes and of consumed sugar in teas or porridges in the 24-hour recalls, that bias the food intake. Another limitation in the Vegi-Leg study, is that we measured deficiencies of micronutrients through dietary intake and hemoglobin, but unfortunately did not take blood samples for the measurement of further biological markers i.e., soluble transferrin receptor and infection markers. Hemoglobin can be measured right on the study sites using a drop of venous blood and a portable battery-operated hemoglobinometer, whereas actual blood sampling require centrifugation on site, immediate refrigeration, freezing and further transportation to Germany, associated with considerable logistical and financial efforts.

Further studies are needed to verify and confirm suggested MUAC cut-offs specific for subgroups e.g. elderly, obese.

Improvements to CIMI, such as automatic calculation of percent fulfillment of nutrient intake recommendation and the ability for respondents to deselect foods within a food group, will further enhance its usability.

Conclusions, outlook and future aspects

The findings confirm an existing triple burden of malnutrition in the rural study regions of Tanzania and Mozambique, characterised by high prevalences of anemia and overweight, among women from Tanzania, and underweight, among men from Mozambique. The increasing rates of overweight are very likely related to food consumption patterns that have changed from consuming fruits, vegetables and fibre-rich foods to refined foods and overall higher amounts of sugar and fats, which are now easily affordable and available even in rural areas. The results showed further, that MUAC has an equivalent diagnostic performance compared to BMI in identifying female and male farmers with underweight, as well as those with overweight. Hence, MUAC can be used for surveillance and screening of malnutrition in adults and adolescents, especially in rural settings where the necessary equipment for BMI measurements is unavailable. Similarly, CIMI algorithm could be a valid and timesaving instrument to estimate nutrient intake in rural areas. Its application provides detailed information for macro- and micronutrient intake in relation to recommended daily intake, without additional time requirement for data input of single foods consumed, as mandatory in using the standard software NutriSurvey.

To combat the increasing prevalence of TBM in rural Tanzania and Mozambique, there is an urgent need to enhance access to micronutrient-rich foods such as vegetables, legumes and fruits, to avoid replacing rural undernutrition disadvantages with malnutrition that involves excessive consumption of low-quality calories e.g., refined sugars and carbohydrates, as well as oils and fats. As sugar was largely consumed in combination with black tea, next to eating habits, changing drinking habits is also an important part of the nutrition transition and needs to receive more attention. Easy-to-use metrics (e.g., MUAC and CIMI) to respectively assess anthropometrics and dietary intake of large populations living in rural resource-poor settings are needed to track contributions of lifestyle and diet quality to the triple burden of malnutrition and to offer tailored interventions to the farmers in Tanzania and Mozambique. The Vegi-Leg approach of implementing innovative processing technologies for nutrient-dense pigeon peas and dark green leafy vegetables to safeguard perennial nutrition security and availability of healthy foods, will very likely help improve the nutritional status of female and male farmers.

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Appendix

Table A1: Food Frequency of all consumed food items per week in Lindi (Tanzania) and Gurue (Mozambique); baseline comparison

Food items, FFQ	Lindi, TZ Baseline	Gurue, MZ Baseline	Mitumbati Baseline	Mibure Baseline	Ruace Baseline	Nicoropale Baseline
N	**670**	**859**	**337**	**333**	**407**	**452**
Maize	12 (7, 14)** 0 - 21	7 (4, 14) 0 - 21	12 (7, 14) 0 - 21	12 (7, 14) 0 - 21	7 (4, 14) 0.5 - 21	6 (3, 7) 0 – 21
Sorghum	0 (0, 0)** 0 – 8	2 (0.5, 3) 0 - 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 8	2 (0.25, 2) 0 - 14	2 (1, 3) 0 - 21
Finger millet	0 (0, 0)** 0 – 7	0 (0, 0) 0 - 5	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0 (0, 0) 0 - 5	0 (0, 0) 0 - 3
Bulrush millet	0 (0, 0)** 0 - 0	0 (0, 0.25) 0 - 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 1) 0 - 6	0 (0, 0.1) 0 - 14
Rice	1 (0, 2)** 0 – 14	2 (1, 4) 0 - 21	2 (0, 3) 0 - 14	1 (0, 2) 0 - 12	2 (1, 4) 0 – 21	2 (1, 4) 0 – 14
Wheat	0 (0, 0)** 0 - 8	0 (0, 0) 0 - 0	0 (0, 0) 0 – 8	0 (0, 0) 0 – 7	0 (0, 0) 0 - 0	0 (0, 0) 0 – 0
Wheat bread	0 (0, 0)** 0 – 12	1 (0.1, 2) 0 – 14	0 (0, 0) 0 – 3	0 (0, 0) 0 – 12	1 (0.1, 2) 0 – 14	1 (0.1, 1) 0 – 7
African donut	0 (0, 2)** 0 – 12	0.25 (0, 2) 0 – 21	0 (0, 2) 0 – 8	0 (0, 2) 0 – 12	0.5 (0, 2) 0 – 21	0.1 (0, 1) 0 – 7
Chapatti	0 (0, 1)** 0 – 8	0 (0, 0) 0 – 1	0 (0, 0) 0 – 7	0 (0, 2) 0 – 8	0 (0, 0) 0 – 0.5	0 (0, 0) 0 – 1
Halfcake	0 (0, 0)** 0 – 2	0 (0, 0) 0 – 14	0 (0, 0) 0 – 2	0 (0, 0) 0 – 1	0 (0, 0) 0 – 14	0 (0, 0) 0 – 3
Round potatoes	0 (0, 0)** 0 – 12	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0 (0, 0) 0 – 12	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7
Cassava	1 (0, 2)** 0 – 21	2 (1, 4) 0 – 14	1 (0, 3) 0 – 14	0 (0, 2) 0 – 21	2 (1, 4) 0 – 14	3 (2, 5) 0 – 14
Irish potatoes	0 (0, 0)** 0 – 5	0 (0, 0.5) 0 – 7	0 (0, 0) 0 – 3	0 (0, 0) 0 – 5	0 (0, 1) 0 – 7	0 (0, 0.5) 0 – 7
Sweet potatoes	0 (0, 2)** 0 – 12	2 (1, 3) 0 – 14	0 (0, 1) 0 – 7	0 (0, 2) 0 – 12	2 (1, 3) 0 – 14	2 (1, 3) 0 – 14
Green banana	0 (0, 0)** 0 – 6	1 (0, 2) 0 – 7	0 (0, 0) 0 – 4	0 (0, 0) 0 – 6	1 (0, 2) 0 – 7	1 (0.5, 2) 0 – 7
Yams	0 (0, 0)** 0 – 4	0 (0, 1) 0 – 5	0 (0, 0) 0 – 4	0 (0, 0) 0 – 3	0 (0, 1) 0 – 5	0 (0, 1) 0 – 4
Pumpkin fruit	0 (0, 0)** 0 – 7	1 (0, 2) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 6	1 (0, 3) 0 – 21	1 (0, 2) 0 – 14
Kidney beans	0 (0, 0)** 0 – 7	2 (1, 3) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 6	2 (1, 3) 0 – 21	2 (1, 3) 0 – 14
Pigeon peas	5 (3, 8)** 0 – 20	4 (2, 5) 0 – 14	6 (3, 12) 0 - 20	4 (2, 7) 0 - 14	4 (2, 5) 0 – 14	4 (2, 5) 0 – 14
Cowpeas	0 (0, 2)** 0 – 14	1 (0.5, 2) 0 – 21	0 (0, 1) 0 - 7	1 (0, 3) 0 - 14	2 (1, 2) 0 – 14	1 (0, 2) 0 – 21
Green grams	0 (0, 0)** 0 – 5	0 (0, 1) 0 – 14	0 (0, 0) 0 – 5	0 (0, 0) 0 – 2	0.1 (0, 1) 0 – 14	0 (0, 0.1) 0 – 6
Chickpeas	0 (0, 0)** 0 – 0	0 (0, 0) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 – 14	0 (0, 0) 0 – 4
Soybeans	0 (0, 0)** 0 – 0	0 (0, 0.25) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.25) 0 – 14	0 (0, 0.1) 0 – 4

Bambara nuts	0 (0, 0)** 0 – 5	0.5 (0, 2) 0 – 14	0 (0, 0) 0 – 5	0 (0, 0) 0 – 2	0.25 (0, 2) 0 – 14	0.5 (0, 2) 0 – 14
Lablab beans	0 (0, 0)** 0 – 0	0.1 (0, 1) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 2) 0 – 14	0.5 (0, 1) 0 – 14
Amaranth leaves	0 (0, 1)** 0 – 7	2 (1, 3) 0 – 21	0 (0, 2) 0 – 7	0 (0, 0) 0 – 5	2 (1, 3) 0 – 21	2 (1, 3) 0 – 14
Pumpkin leaves	0 (0, 0)** 0 – 14	2 (1, 3) 0- 21	0 (0, 0) 0 – 14	0 (0, 1) 0 – 12	2 (1, 3) 0 – 21	2 (1, 2) 0 – 21
Moringa leaves	0 (0, 0)** 0 – 0	0 (0, 1) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0.1 (0, 2) 0 – 14	0 (0, 1) 0 – 5
S. potato leaves	0 (0, 0)** 0 – 7	2 (1, 3) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 6	2 (1, 3) 0 – 21	2 (1, 2) 0 – 14
Cassava leaves	0 (0, 0)** 0 – 7	2 (1, 2) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 5	1 (0.5, 2) 0 – 21	2 (1, 3) 0 – 14
Cowpea leaves	0 (0, 1)** 0 – 9	1 (0.1, 2) 0 – 21	0 (0, 0) 0 – 7	0 (0, 2) 0 – 9	2 (0.5, 2) 0 – 21	1 (0, 2) 0 – 14
Okra leaves	0 (0, 0)** 0 – 1	1 (0, 2) 0 – 21	0 (0, 0) 0 – 0	0 (0, 0) 0 – 1	1 (0, 2) 0 – 21	1 (0, 1) 0 – 14
Naconha	0 (0, 0)** 0 – 0	0 (0, 1) 0 -14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 1) 0 – 14	0 (0, 0.5) 0 – 14
Candrua	0 (0, 0)** 0 – 0	0 (0, 0) 0 -14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.1) 0 – 14	0 (0, 0) 0 – 7
Tutuli	0 (0, 0)** 0 – 0	0 (0, 1) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 1) 0 – 14	0 (0, 1) 0 -14
Txitxiwiri	0 (0, 0)** 0 – 0	0 (0, 0) 0 – 4	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 – 4	0 (0, 0) 0 – 3
Naminha	0 (0, 0)** 0 – 0	0 (0, 1) 0 – 21	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0.25 (0, 1) 0 – 21	0 (0, 1) 0 – 14
Jute mallow	0 (0, 0)** 0 – 2	0.25 (0, 1) 0 – 14	0 (0, 0) 0 – 2	0 (0, 0) 0 – 2	0.25 (0, 2) 0 – 14	0.1 (0, 1) 0 – 14
Namualicon a	0 (0, 0)** 0 – 0	0 (0, 1) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 1) 0 – 7	0 (0, 0.5) 0 – 14
Mulhace	0 (0, 0)** 0 – 0	0 (0, 0.5) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.25) 0 – 14	0 (0, 1) 0 – 14
Mlenda ilende	0 (0, 0)** 0 – 3	0 (0, 0) 0 – 0	0 (0, 0) 0 – 3	0 (0, 0) 0 – 1	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0
Spinach	0 (0, 0)** 0 – 4	0 (0, 0) 0 – 0	0 (0, 0) 0 – 4	0 (0, 0) 0 – 3	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0
Cabbage	0 (0, 0)** 0 – 3	2 (2, 4) 0 – 21	0 (0, 0) 0 – 3	0 (0, 0) 0 – 3	3 (2, 4) 0 – 21	2 (2, 3) 0 – 14
Chinese cabbage	0 (0, 0)** 0 – 5	0 (0, 1) 0 – 14	0 (0, 1) 0 – 5	0 (0, 0) 0 – 4	0 (0, 1) 0 – 14	0 (0, 1) 0 – 14
Carrots	0 (0, 0)** 0 – 7	0 (0, 0.25) 0 – 7	0 (0, 0) 0 – 2	0 (0, 0) 0 – 7	0 (0, 0.25) 0 – 7	0 (0, 0.5) 0 – 4
Tomatoes	5 (0, 7)** 0 – 18	14 (6, 14) 0 – 21	3 (0, 7) 0 – 14	7 (3, 7) 0 - 18	14 (6, 14) 0 – 21	14 (6, 21) 0 – 21
African eggplant	0 (0, 0)** 0 – 5	0 (0, 0.5) 0 – 21	0 (0, 0) 0 – 0	0 (0, 0) 0 – 5	0 (0, 0.1) 0 – 14	0 (0, 0.5) 0 – 21
Eggplant	0 (0, 0)** 0 – 14	0 (0, 0.1) 0 – 14	0 (0, 0) 0 – 2	0 (0, 0) 0 – 14	0 (0, 0.1) 0 – 14	0 (0, 0.1) 0 – 4
Onions	5 (0, 7)** 0 – 18	7 (4, 14) 0 – 21	3 (0, 7) 0 - 14	7 (3, 7) 0 - 18	7 (5, 14) 0 – 21	7 (4, 14) 0 – 21
Okra	0 (0, 0)** 0 – 7	1 (0, 2) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	1 (0, 2) 0 – 21	0.5 (0, 2) 0 – 14
Sweet pepper	0 (0, 0)** 0 – 7	0 (0, 1) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 3	0 (0, 1) 0 – 14	0 (0, 0.5) 0 – 21

Mushrooms	0 (0, 0)** 0 – 0	0.1 (0, 2) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0.1 (0, 2) 0 – 7	0.25 (0, 2) 0 – 14
Oranges	2 (0, 5)** 0 – 25	2 (0.5, 3) 0 – 21	2 (0, 5) 0 - 25	2 (0, 5) 0 - 25	2 (1, 3) 0 – 21	2 (0.5, 2) 0 – 21
Tangerine	0 (0, 0)** 0 – 7	1 (0, 2) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 3	1 (0, 2) 0 – 21	1 (0, 2) 0 – 21
Grapefruit	0 (0, 0)** 0 – 0	0 (0, 0) 0 – 3	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 – 3	0 (0, 0) 0 – 1
Mango	0 (0, 0)** 0 – 7	1 (0, 7) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0.1 (0, 7) 0 – 21	1 (0, 14) 0 – 21
Passion fruit	0 (0, 0)** 0 – 0	0 (0, 0) 0 – 21	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 – 21	0 (0, 0.1) 0 – 7
Watermelon	0 (0, 0)** 0 – 3	0 (0, 1) 0 – 14	0 (0, 0) 0 – 2	0 (0, 0) 0 – 3	0 (0, 1) 0 – 14	0 (0, 0.1) 0 – 4
Banana	0 (0, 0)** 0 – 7	2 (1, 4) 0 – 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	2 (1, 3) 0 – 21	2 (1, 4) 0 – 14
Pineapple	0 (0, 0)** 0 – 3	0 (0, 0.1) 0 – 14	0 (0, 0) 0 – 3	0 (0, 0) 0 – 0	0 (0, 0.1) 0 – 14	0 (0, 0.1) 0 – 14
Papaya	0 (0, 0)** 0 – 14	1 (0.25, 3) 0 – 21	0 (0, 1) 0 – 14	0 (0, 0) 0 – 7	2 (0.25, 3) 0 – 21	1 (0.1, 2) 0 – 14
Baobab	0 (0, 0)** 0 – 2	0 (0, 0) 0 – 7	0 (0, 0) 0 – 2	0 (0, 0) 0 – 0	0 (0, 0) 0 – 7	0 (0, 0) 0 – 3
Guava	0 (0, 0)** 0 – 3	0 (0, 1) 0 – 14	0 (0, 0) 0 – 3	0 (0, 0) 0 – 0	0 (0, 1) 0 – 14	0 (0, 1) 0 – 7
Wild fruits	0 (0, 0)** 0 – 0	0 (0, 0.25) 0 – 7	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.25) 0 – 7	0 (0, 0.25) 0 – 4
Avocado	0 (0, 0)** 0 – 5	0.25 (0, 1) 0 – 21	0 (0, 0) 0 – 5	0 (0, 0) 0 – 0	0.1 (0, 1) 0 – 21	0.25 (0, 1) 0 – 21
Lemon	0 (0, 0)** 0 - 3	0 (0, 0) 0 - 0	0 (0, 0) 0 – 3	0 (0, 0) 0 – 0	0 (0, 0) 0 - 0	0 (0, 0) 0 – 0
Soursop	0 (0, 0)** 0 - 3	0 (0, 0) 0 - 0	0 (0, 0) 0 – 2	0 (0, 0) 0 – 3	0 (0, 0) 0 - 0	0 (0, 0) 0 - 0
Groundnuts	0 (0, 1)** 0 - 14	3 (2, 4) 0 - 21	0 (0, 1) 0 – 14	0 (0, 1) 0 – 8	2 (1, 4) 0 - 21	3 (2, 5) 0 - 21
Coconut	0 (0, 0)** 0 - 10	0 (0, 1) 0 - 14	0 (0, 0) 0 – 10	0 (0, 0) 0 – 5	0.1 (0, 1) 0 - 7	0 (0, 1) 0 - 14
Cashew nut	0 (0, 0)** 0 – 5	0 (0, 0) 0 – 14	0 (0, 0) 0 – 4	0 (0, 0) 0 – 5	0 (0, 0) 0 – 14	0 (0, 0) 0 – 0.25
Sesame	0 (0, 0)** 0 - 12	0 (0, 0) 0 - 0	0 (0, 0) 0 – 12	0 (0, 0) 0 – 10	0 (0, 0) 0 - 0	0 (0, 0) 0 - 0
Butter/ Margarine	0 (0, 0)** 0 - 0	0 (0, 0) 0 - 7	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.1) 0 - 7	0 (0, 0) 0 - 7
Sunflower oil	0 (0, 0)** 0 – 28	0.1 (0, 4) 0 - 21	0 (0, 0) 0 – 28	0 (0, 0) 0 – 21	2 (0, 5) 0 - 21	0 (0, 4) 0 - 21
Red palm oil	0 (0, 0)** 0 – 14.5	0 (0, 0) 0 - 2	0 (0, 0) 0 – 14	0 (0, 0) 0 – 14.5	0 (0, 0) 0 - 2	0 (0, 0) 0 - 2
Vegetable oil	0 (0, 7)** 0 - 18	4 (2, 14) 0 - 21	0 (0, 7) 0 – 18	0 (0, 7) 0 – 16	5 (2, 14) 0 - 21	4 (2, 7) 0 - 21
Groundnut oil	0 (0, 0)** 0 - 14	0 (0, 0) 0 – 14	0 (0, 0) 0 – 7	0 (0, 0) 0 – 14	0 (0, 0) 0 - 7	0 (0, 0) 0 - 14
Fresh fish	0 (0, 0)** 0 - 3	1 (0.5, 2) 0 - 14	0 (0, 0) 0 – 3	0 (0, 0) 0 – 3	1 (1, 2) 0 - 14	1 (0.1, 1) 0 - 5
Dried fish	0 (0, 1)** 0 - 7	2 (1, 3) 0 - 14	0 (0, 1) 0 – 7	0 (0, 1) 0 – 5	2 (2, 3) 0 - 14	2 (1, 3) 0 - 14

Sardines	0 (0, 1)** 0 - 14	0 (0, 0) 0 - 5	0 (0, 1) 0 – 14	0 (0, 0) 0 – 5	0 (0, 0) 0 - 4	0 (0, 0) 0 - 5
Seafood	0 (0, 0)** 0 – 22	0 (0, 0) 0 - 4	0 (0, 0) 0 – 2	0 (0, 0) 0 – 22	0 (0, 0) 0 - 3	0 (0, 0) 0 - 4
Rodent meat	0 (0, 0)** 0 – 3	3 (1, 4) 0 - 14	0 (0, 0) 0 – 1	0 (0, 0) 0 – 3	2 (1, 4) 0 - 14	3 (1, 4) 0 - 14
Insect meat	0 (0, 0)** 0 – 0	0 (0, 0.1) 0 – 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0.1) 0 - 14	0 (0, 0) 0 - 2
Beef	0 (0, 0)** 0 – 7	0 (0, 0.1) 0 – 4	0 (0, 0) 0 – 7	0 (0, 0) 0 – 4	0 (0, 0.1) 0 - 4	0 (0, 0.1) 0 - 4
Pork	0 (0, 0)** 0 – 6	0.1 (0.1, 1) 0 - 7	0 (0, 0) 0 – 2	0 (0, 0) 0 – 6	0.25 (0.1, 1) 0 - 7	0.1 (0, 0.25) 0 - 4
Lamb	0 (0, 0)** 0 - 0	0 (0, 0) 0 - 3	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 - 2	0 (0, 0) 0 - 3
Goat	0 (0, 0)** 0 - 3	0.1 (0, 0.25) 0 – 4	0 (0, 0) 0 – 2	0 (0, 0) 0 – 3	0.1 (0, 0.25) 0 - 4	0.1 (0, 0.1) 0 - 2
Donkey	0 (0, 0)** 0 – 0	0 (0, 0) 0 - 2	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 - 2	0 (0, 0) 0 - 2
Rabbit	0 (0, 0)** 0 – 2	0 (0, 0.1) 0 - 14	0 (0, 0) 0 – 2	0 (0, 0) 0 – 0	0 (0, 0.1) 0 - 14	0 (0, 0) 0 - 2
Poultry	0 (0, 0)** 0 – 14	0.25 (0.1, 1) 0 - 14	0 (0, 0) 0 – 14	0 (0, 0) 0 – 12	0.5 (0.1, 2) 0 - 14	0.25 (0.1, 1) 0 - 14
Liver	0 (0, 0)** 0 – 0	0 (0, 0) 0 - 14	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 - 14	0 (0, 0) 0 - 7
Eggs	0 (0, 0)** 0 – 7	0.25 (0.1, 1) 0 - 21	0 (0, 1) 0 – 7	0 (0, 0) 0 – 7	0.5 (0, 1) 0 - 21	0.25 (0.1, 1) 0 - 4
Cow milk	0 (0, 0)** 0 – 7	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0 (0, 0) 0 - 7	0 (0, 0) 0 - 2
Goat milk	0 (0, 0)** 0 – 0	0 (0, 0) 0 – 0.5	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0.5	0 (0, 0) 0 - 0
Processed packed milk	0 (0, 0)** 0 – 7	0 (0, 0) 0 - 7	0 (0, 0) 0 – 0	0 (0, 0) 0 – 7	0 (0, 0) 0 - 7	0 (0, 0) 0 - 7
Yoghurt	0 (0, 0)** 0 – 7	0 (0, 0) 0 - 2	0 (0, 0) 0 – 0	0 (0, 0) 0 – 7	0 (0, 0) 0 - 2	0 (0, 0) 0 - 1
Sugar	5 (1, 7)** 0 – 14	1 (0.5, 3) 0 - 14	5 (2, 7) 0 - 14	4 (0.25, 7) 0 - 14	2 (1, 4) 0 - 14	1 (0.5, 2) 0 - 7
Sugarcane	0 (0, 0)** 0 – 7	3 (2, 5) 0 - 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	3 (1, 5) 0 - 21	3 (2, 5) 0 - 14
Honey	0 (0, 0)** 0 - 1	0 (0, 0) 0 - 7	0 (0, 0) 0 – 0	0 (0, 0) 0 – 1	0 (0, 0) 0 - 4	0 (0, 0) 0 - 7
Sweetened soda	0 (0, 0)** 0 – 14	0 (0, 0.25) 0 - 21	0 (0, 0) 0 – 4	0 (0, 0) 0 – 14	0.1 (0, 1) 0 - 21	0 (0, 0.1) 0 - 7
Sweetened juices	0 (0, 0)** 0 – 7	1 (0, 2) 0 - 21	0 (0, 0) 0 – 5	0 (0, 0) 0 – 7	0.5 (0, 2) 0 - 21	1 (0, 2) 0 - 7
Chocolate	0 (0, 0)** 0 – 0	0 (0, 0) 0 - 3	0 (0, 0) 0 – 0	0 (0, 0) 0 – 0	0 (0, 0) 0 - 3	0 (0, 0) 0 - 1
Candies	0 (0, 0)** 0 – 7	0 (0, 0) 0 - 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 7	0 (0, 0.25) 0 - 21	0 (0, 0) 0 - 2
Cookies	0 (0, 0)** 0 - 2	0 (0, 0) 0 - 7	0 (0, 0) 0 – 2	0 (0, 0) 0 – 1	0 (0, 0) 0 - 7	0 (0, 0) 0 - 3
Coffee	0 (0, 0)** 0 – 7	0 (0, 0) 0 - 7	0 (0, 0) 0 – 2	0 (0, 0) 0 – 7	0 (0, 0) 0 - 7	0 (0, 0) 0 - 3

Tea	5 (1, 7)** 0 – 14	1 (0, 2) 0 - 14	6 (2, 7) 0 - 14	4 (0, 7) 0 - 14	1 (0.1, 3) 0 - 14	0.5 (0, 1) 0 - 7
Local Brew	0 (0, 0)** 0 – 20	1 (0, 2) 0 - 21	0 (0, 0) 0 – 20	0 (0, 0) 0 – 14	1 (0, 2) 0 - 21	1 (0, 2) 0 - 21
Beer	0 (0, 0)** 0 - 7	0 (0, 0.1) 0 - 21	0 (0, 0) 0 – 7	0 (0, 0) 0 – 4	0 (0, 0.1) 0 - 21	0 (0, 0) 0 - 5
Wine	0 (0, 0)** 0 - 1	0 (0, 0) 0 - 21	0 (0, 0) 0 – 1	0 (0, 0) 0 – 0	0 (0, 0) 0 - 21	0 (0,0) 0 - 14

Figures are median (interquartile range - IQR) and range of food consumption per week, all such values. P-Values: Kruskal-Wallis (median) test; all p-values** were <0.001

Table A2. Weight lists in grams (portions sizes 24 hour recalls)

Food item:	**Weight in grams [g]**
1. Groundnuts with peel:	
A-1/2 handful	25g
B- 1 handful	50g
C- 2 handful	100g
2. Groundnuts peeled:	
A-1/2 handful	25g
B- 1 handful	50g
C- 2 handful	100g
3. Cashews:	
A-1/2 handful	30g
B- 1 handful	60g
C- 2 handful	120g
4. Sugar:	
A- teaspoon	12g
B- 1 heaped tablespoon	25g
C- 1/3 cup	100g (100ml)
D-2/3 cup	200g (200ml)
E- 1 full cup	300g (300ml)
5. Maize ugali	
A-1 small handful	250g (125g flour + 125g water)
B-1 big handful	500g (250g flour + 250g water)

C- 2 handful	1000g (500g flour + 500g water)
6. Cassava ugali	
A-1 small handful	250g (125g flour + 125g water)
B-1 big handful	500g (250g flour + 250g water)
C- 2 handful	1000g (500g flour + 500g water)
7. Maize porridge (uji)	
A-1 half-full bowl	250g (62,5g flour + 187,5g water)
B-1 full bowl	500g (125g flour + 375g water)
C- 2 full bowls	1000g (250g flour + 750g water)
8. Green leafy vegetables ("Mlenda")	
A-1/4 full plate	60g (+30ml water)
B- 1/3 full plate	125g (+75ml water)
C- ½ full plate	250g (+150ml water)
D- 1 full plate	500g (+300ml water)
9. Extras:	
A-Okra (5 pieces)	72g (1 Okra= 12g)
B-Okra (10 pieces)	140g
A-Tomato (1 piece)	110g
B-Tomato (2 pieces)	220g
A-onion (1 piece)	60g
B-onion (2 pieces)	120g
10. Rice	
A-1/4 full plate	125g (40g rice+ 85g water)
B- 1/3 full plate	250g (75g rice + 175g water)
C- ½ full plate	500g (150g rice + 350g water)
D- 1 full plate	1000g (300g rice + 700g water)
11. Cowpeas:	

A-1/2 full plate	125g (62,5g cowpeas +125g water)
B-1 full plate	250g (125g cowpeas + 125g water)
C-1 overfull plate	500g (250g cowpeas + 250g water)
12. Pigeon Peas:	
A-1/2 full plate	125g (62,5g PP +125g water)
B-1 full plate	250g (125g PP + 125g water)
C-1 overfull plate	500g (250g PP + 250g water)

Table A3: Description of the food groups in CIMI-algorithm

	Food Group	Contributing food items *(% contents of each food)*
1.	Maize	Maize flour dry (100%)
2.	Bulrush millet	Bulrush millet dry (100%)
3.	Sorghum	Sorghum flour dry (100%)
4.	Fried Bakery	Chapatti, African Donuts, Bhajia ->All three food items have an average contribution of 33.33%
5.	Other cereals	Rice (60%), finger millet (20%), wheat (20%)
6.	Plantain, white roots and tubers	Cooked bananas (30%), cassava (25%), white sweet potatoes (25%), potatoes (20%)
7.	Nuts	Groundnuts (90%), cashew nuts (10%)
8.	Pulses	Beans (kidney), cowpeas, pigeon peas, green grams, chicken peas, soya beans, Bambara nuts, lablab beans (hyacinths beans) ->All eight food items have an average contribution of 12.5%
9.	Vitamin A rich vegetables and yellow tubers	Yellow sweet potatoes (60%), pumpkin (25%), carrots (15%)
10.	Green leafy vegetables	Mlenda (35%) [= Corchorus trilocularis/Mugunda (10%) + Ceratotheca sesamoides/Ilende (25%)], cowpea leaves (20%), amaranth (10%), sweet potato leaves (10%), Chinese cabbage (10%), cassava leaves (5%), spinach (5%), pumpkin leaves (5%)
11.	Other vegetables	Tomatoes (30%), onions (30%), African eggplant (30%), eggplant (5%), green pepper (5%)
12.	Meat	Beef (50%), chicken (15%), goat (15%), lamb (15%), pork (5%)

13.	Organ meat	Beef tripe (60%), beef liver (40%),
14.	Eggs	Chicken egg boiled (50%), chicken egg fried (50%)
15.	Milk and milk products	Yogurt (55%), cow's whole fat milk (40%), milk powder (5%)
16.	Fish (all types)	Sardines (40%), fish relish (30%), fried fish (20%), smoked fish (10%),
17.	Vitamin A rich fruits-A	Mangoes (50%), papaya (50%)
18.	Other fruits	Oranges (30%), watermelon (30%), ripe bananas (30%), pineapple (5%), avocado (5%)
19.	Red palm oil	Palm oil (100%)
20.	Other oils and fats	Coconut cream (60%), vegetable oil (40%)
21.	Added sugar/honey	Sugar (90%), honey (10%)
22.	Soft drinks	Carbonated drinks, Coca-Cola, fruit flavored drinks ->All three food items have an average contribution of 33.33%
23.	Beer/ local brews	Beer local grain (90%), beer commercial (5%), beer local-nonspecific (5%)

Shares of authors contributing to the thesis

Laila Eleraky, the candidate, took part in the field studies and performed the data entry including all principal statistical and analytical work unless not otherwise stated below. She performed the data analysis and interpretation of the results. Except the shares listed below, she wrote and prepared this thesis and all manuscripts including their tables and figures.

Prof. Jan Frank is the supervisor of this work. He proofread the manuscripts and this thesis.

Dr. Wolfgang Stuetz was involved in defining the overall research aim and supported the statistical analysis. He actively supervised the dissertation and contributed to the conceptualization and design of this work. He was involved in writing and proofreading all manuscripts. He was responsible for all formal aspects of the publication process.

Dr. Christine Lambert was involved in conceptualizing the CIMI paper and was responsible for the formal aspects of its publication process.

M. Sc. Jannik Orthober evaluated the FFQ and HDDS.

Dr. Constance Rybak, **Dr. Hadijah Mbwana**, **Prof. Sónia Maciel**, **Ramula Issa**, **Prof. Hans Konrad Biesalski** and **Prof. Joyce Kinabo** are co-authors of the included publications and proofread them.

Prof. Johanita Kruger proofread all publications and this dissertation

Contributions to publications

Publication	**Author Contribution**
High Prevalence of Overweight and Its Association with Mid-Upper Arm Circumference among Female and Male Farmers in Tanzania and Mozambique	S.M., H.M., C.R. and W.S. designed the research; L.E., R.I. and W.S. conducted the field study; L.E. and W.S. carried out data and statistical analysis; L.E. wrote the manuscript, and C.R., J.F. and W.S provided significant advice and critically edited the manuscript. All authors have read and agreed to the published version of the manuscript.
Anthropometrics, Hemoglobin Status and Dietary Micronutrient Intake among Tanzanian and Mozambican Pigeon Pea Farmers	S.M., H.M., C.R. and W.S. designed the research; L.E., R.I. andW.S. conducted the field study; L.E. andW.S. carried out data and statistical analysis; L.E. wrote the manuscript; C.R., J.F. and W.S. provided significant advice and critically edited the manuscript. All authors have read and agreed to the published version of the manuscript.
Potentials and limitations of a food-group based algorithm to assess dietary nutrient intake of women in rural areas in Tanzania	Conception and design of the study: WS, CR, JF, HKB, HM, JK, CL; Generation, collection, assembly of data: LE, WS, CR, HM; Analysis and/or interpretation of data: LE, WS, CL, JK, HM Drafting/revision of the manuscript: LE, CL, WS, JK, HKB Approval of the final version of the manuscript: LE, WS, CR, JF, HKB, HM, JK, CL

I hereby confirm the candidate's declaration of her contributions and the contributions of her co-authors in the thesis.

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