Food insecurity, Nutrition and Health Status in Unguja, Zanzibar

Dissertation

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vorgelegt von

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Hiermit erkläre ich, Maria Adam Nyangasa-Ambe, geboren in Dar-es-Salaam, Tanzania, dass für das Verfassen der vorliegenden Dissertation „Food insecurity, Nutrition and Health Status in Unguja, Zanzibar“ folgende drei Aussagen zutreffen:

1. Ich habe die Arbeit ohne unerlaubte fremde Hilfe angefertigt,
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Summary

Data from epidemiological studies that investigate food insecurity, health and nutrition status and includes the entire household members is very rare in sub-Saharan Africa. This thesis, with the scope of a project, *"Access to Food and Nutrition Status of the Zanzibari Population*" is the first in Tanzania to investigate and report potential role of socio- demographic factors of food access, food insecurity and food consumption and the implications for health, nutrition and inflammatory response including all members living in the same household.

The present thesis investigated the prevalence of malnutrition in the study population and provided population-based data on food consumption and individual dietary diversity. Furthermore, the theses investigated the relationship between food access and sociodemographic correlates with food consumption score and food insecurity experience scale. Specific anthropometric indices of malnutrition were used to investigate and determine their association to cardio-metabolic risk factors, leptin and inflammatory markers.

The cross-sectional population-based survey – providing the data for the individual papers of this theses - was conducted in 2013 and included 80 randomly selected Shehias (wards) in Unguja Island. Anthropometric data (weight, height, mid-upper arm circumference, waist and hip circumference, and body composition) and face-to-face interviews were assessed for all members in the household. Furthermore, blood pressure and bio-samples; urine and blood were also collected.

The study recruited 1314 participants of which 54.54% were female. The overall mean age was 23.6 ± 18.9 years ranging between 0-95 years. The overall prevalence of underweight in the study population was 36.53% with the highest prevalence in children under 14 years. The prevalence of overweight and obesity in the study population was 13.10% and 8.14% respectively; with the highest prevalence in women. Furthermore, the study reported 65% of the surveyed households had poor food consumption and about one-third (32%) were severe food insecure. Severe food insecurity was more prevalent in polygamous households and larger households, even in the interaction with poor FA; larger households were associated with severe food insecurity.

About 29% of the participants above 5 years had abnormal values of low high-density lipoprotein cholesterol (HDL-C) (29%) with the highest prevalence observed in participants aged ≥18 to <45 years. Hypertension increased with age, and was most prevalent in participants aged 45 years and above. High levels of low low-density lipoprotein cholesterol in the study population was associated with high waist circumference and high percentage body fat (OR=2.52 (95% CI 1.24 to 5.13), OR=1.91 (95% CI 1.02 to 3.58), respectively. Additionally, BMI and WC were associated with high levels of HbA1c (OR=2.08 (95% CI 1.15 to 3.79), OR=3.01 (95% CI 1.51 to 6.03), respectively. Nevertheless,

individuals with high waist circumference were twice more likely to have hypertension compared to those with high BMI and high percentage body fat. On the contrary, in another publication with a slightly larger sample, thinness was reported to be associated with hypertension. Also, observed in children a significant reduced chance of hypertension for higher urinary sodium-to-potassium compared to a lower ratio.

In the association between obesity indices and inflammatory markers, the study reported strong association between obesity with leptin and CRP in the highest quartiles. However, in the combined models, the associations were observed between BMI (OR =6.36 [95% CI, 1.09; 34.12]); WC (OR = 4.87 [95% CI, 1.59; 14.94]); and % BF (OR= 19.23 [95% CI, 4.70; 78.66]) and leptin in the fourth quartile; also, between %BF and CRP in the third quartile (OR = 3.49 [95% CI 1.31; 9.31]).

Malnutrition exists in communities as a result of food and nutrition insecurity which is affected by several factors that need to be addressed. Community based-interventions are needed to increase awareness of malnutrition and its consequences in the community by targeting the risk factors for primary prevention. Local institutions should form a fundamental part of the strategy to fight malnutrition in the general population and especially in at-risk groups, including the elderly. Nutrition interventions on healthier diets and improved methods of food preparation, encouragement on physical activity should be key parts of care planning to improve health status and quality of life.

Additionally, secondary prevention measures are needed to target those at high risk by conducting early routine screening.

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List of Publications

Original research articles addressing the thesis

The present cumulative doctoral theses have resulted thus far in five original research articles, published in international peer-reviewed open access journals.

Published

1 **Nyangasa MA**, Kelm S., Sheikh M, Hebestreit A. Design, Response Rates, and Population Characteristics of a Cross-Sectional Study in Zanzibar, Tanzania, JMIR Res Protoc, 2016 **5**(4): p. e235. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5159612/

2 **Nyangasa MA,** Buck C, Kelm S, Sheikh M, Hebestreit A. Exploring Food Access and Sociodemographic Correlates of Food Consumption and Food Insecurity in Zanzibari Households. May 4, 2019. International Journal of Environmental Research and Public Health. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6539455/

3 **Nyangasa MA,** Buck C, Kelm S, Sheikh M, Brackmann LK, Hebestreit A. Association between cardio-metabolic risk factors and body mass index, waist circumferences and body fat percent in a Zanzibari cross-sectional study. July 4, 2019. BMJ Open https://bmjopen.bmj.com/content/9/7/e025397

4 **Nyangasa MA,** Buck C, Kelm S, Sheikh M, Günther K, Hebestreit A. The association between leptin and inflammatory markers with obesity indices in Zanzibari children, adolescents, and adults. 22 October 2020. Obesity Science and Practice. https://onlinelibrary.wiley.com/doi/10.1002/osp4.466

Co-author

5. Brackmann LK, Buck C, **Nyangasa MA**, Kelm S, Sheikh M, Hebestreit A. Anthropometric and biological predictors for hypertension in a cross-sectional study in Zanzibar, Tanzania. November 24, 2019. Frontiers in Public Health. https://www.frontiersin.org/articles/10.3389/fpubh.2019.00338/full

Further publications and Presentations

Poster presentations by author and co-authors

Conferences

1. **Nyangasa MA**, Kelm S, Sheikh M, Hebestreit A Distribution of cardio-metabolic risk factors in a Zanzibari population: A cross-sectional study. Poster presentation at the 12th European Nutrition Conference FENS in Berlin September 2015 and during the 10th German Society for Epidemiology (DGEpi) conference Berlin October 2015.

2. Hebestreit A, Buck C, Kelm S, Sheikh M, Brackmann LK, **Nyangasa MA**. Association between cardio-metabolic risk factors and body mass index, waist circumferences and body fat in a Zanzibari cross-sectional study. 25th European Congress on Obesity (ECO), 23-26 May 2018, Vienna, Austria. (Abstract published in: Obesity Facts. 2018;11(Suppl.1):164)

3. Brackmann K, Buck C, **Nyangasa MA,** Kelm S, Sheikh M, Hebestreit A. Anthropometric and biochemical predictors for hypertension in a cross-sectional study in Zanzibar, Tanzania. 13. Jahrestagung der Deutschen Gesellschaft für Epidemiologie (DGEpi), 26.-28. September 2018, Bremen.

Final Symposium

4. **Nyangasa MA**, Kelm S, Sheikh M, Hebestreit A (2016) Determinants of Food Consumption and Food security in a Representative sample of a Zanzibari Population. Poster and Oral presentation at the Final SUTAS Symposium and at a workshop with Zanzibari Shehas in September 2016, Stone Town, Zanzibar.

5. **Nyangasa MA**, Kelm S, Sheikh M, Hebestreit A (2016) Association between Obesity indices and Cardio-metabolic risk factors in a Zanzibari population. Poster and Oral presentation at the Final SUTAS Symposium and at a workshop with Zanzibari Shehas in September 2016, Stone Town, Zanzibar.

Dissemination

6. **Nyangasa MA**, Kelm S, Sheikh M, Hebestreit A. Access to Food and Nutritional Status of the Zanzibari population. Poster presentation at the Zanzibar Innovation Day in December 2013, Unguja Zanzibar.

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List of abbreviations

%BF	Percentage Body Fat
ABSI	Body Shape Index
BMI	Body Mass Index
CI	Confidence Limits
COVID-19	Coronavirus disease 2019
CRP	C-Reactive Protein
DBP	Diastolic Blood Pressure
FA	Food Access
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
FIES	Food Insecurity Experience Scale
FPG	Fasting Plasma Glucose
GLIMMIX	Mixed Logistic Regression Models Based On
Hba1	Glycated Haemoglobin
Hba1c	Glycated Haemoglobin
HDL-C	High Density Lipoprotein-Cholesterol
HH	Head of Household
HOMA-IR	Homeostasis Model Assessment of Insulin Resistance
ICC	Intraclass Correlation Coefficient
IDDS	Individual Dietary Diversity Score
IDF	International Diabetes Federation
IL-6	Interleukin-6
IPC	Integrated Food Security Phase Classification
ISAK	International Society for the Advanced of Kinanthropometry
ISCED	International Standard Classification of Education
LDL-C	Low-Density-Lipoprotein Cholesterol
MVPA	Moderate-To-Vigorous Physical Activity
NCDs	Non-Communicable Diseases
NCEP	National Cholesterol Education Program
OR	Odds Ratios

Q–Q	Quantile-Quantile
SAS 9.3	Statistical Software 9.3
SBP	Systolic Blood Pressure
SD	Standard Deviations
SUZA	State University of Zanzibar
TC	Total Cholesterol
TDHS	Tanzanian Demographic Health Survey
TEM	Technical Error of Measurement
TG	Triglycerides
TNFC	Tanzania Nutrition and Food Centre
TNF-A	Tumour Necrosis Factor
UNICEF	United Nations Children's Fund
WC	Waist Circumference
WHR	Waist-To-Hip Ratio

1 Introduction

Globally, there is an increasing burden of non-communicable diseases (NCDs) and the deaths due to NCDs affect people of all age groups, regions and countries. In 2016, it was estimated about 71% of death worldwide were from NCDs[1], of which, about 23.6 million deaths were the elderly population aged 70 and above, about 15 million deaths between the age group 30-70 years and about 1.7 million deaths was estimated in individuals younger than 30 years[1]. The most prominent NCDs includes cardiovascular diseases, diabetes mellitus, chronic respiratory diseases and cancers [2]which were estimated to cause about 80% of death globally[1].

The highest risk of death due to NCD was observed in low-and-middle-income countries where more than three quarters (31.4 million) of global NCD death occur[2], especially in sub-Saharan Africa (SSA) [1]. According to WHO 2021 [2], cardiovascular diseases (CVDs) account for the most NCD death followed by cancers, respiratory diseases and diabetes with estimated annual deaths of 17.9 million, 9.3 million, 4.1 million and 1.5 million respectively. The burden of these conditions affects countries worldwide but with a growing trend in developing countries. In 2013, it was estimated 1 million deaths were attributed to CVD in Sub-Saharan Africa (SSA) [3] and by 2030 the CVD burden is expected to double[4].

In Tanzania like many developing countries the burden of NCDs has been increasing steadily [5], in 2010 the WHO country estimates reported 27% of all deaths in Tanzania were due to NCDs [6]. In Tanzania communicable diseases account for 65% of all deaths, but also non-communicable disease contribute significantly to disease burden such as CVD which accounted for 12%, cancer (3%), respiratory diseases (3%) and diabetes (2%) [6]. Like many other countries in the world, Tanzania is also undergoing epidemiological transitions from communicable to non-communicable diseases (NCDs) that have been closely linked to increased urbanization and rural-urban migration, which has led to unhealthy behaviours, including poor dietary habits and sedentary lifestyles[7-10].

Overweight and obesity have frequently been associated with the presence of one or more of the NCDs and have been reported to increase the risk for diet-related NCDs. Tanzania is also struggling with the double burden of Malnutrition (DBM) [11] which is characterised as “early life under nutrition and later overweight” [12] thus putting at risk those in rural and remote areas with limited resources and poor infrastructure and on the other side, poor dietary habits and sedentary lifestyle in the urban population [13, 14].

Exposure to malnutrition is reported to be driven by socio-demographic factors including educational level, socioeconomic class, gender etc.[15], thus higher socio-demographic status and living in urban areas have been reported to be positively related with markers of over nutrition such as obesity and NCDs [16-18]. Furthermore, the high costs in the urban areas make it difficult for families to afford cost of food, thus leaving them food insecure and as a result suffer from malnutrition. Additionally, in Cameroon, Ghana, Nigeria and Zanzibar malnutrition has been associated with education level, household size, and/or place of residence [15, 19]; food and nutrition insecurity in these countries has been reported as the leading cause of malnutrition[20].

Furthermore, urbanization and globalization have been linked to nutrition transition in developing countries [21] which result to rapidly increasing levels of obesity, type 2 diabetes, hypertension and dyslipidaemia. Dyslipidaemia is a risk factor for a variety of cardiovascular diseases and is becoming more prevalent in sub-Saharan Africa, particularly high density lipoprotein-cholesterol (HDL-C) [9]. Furthermore, about 12 million people in Africa are estimated to have type 2 diabetes mellitus [22], with the prevalence ranging from 1% in rural Uganda to 12% in urban Kenya [9]. Unlike in the Tanzania Mainland, in Zanzibar there no population-based data reporting the increasing rates of NCDs. However, number of admissions to the hospitals due to Diabetes and CVDs has been increasing recently. Deaths due to CVDs as recorded in the hospitals in Zanzibar accounts for 13-18%[23].

In order to develop alternative and effective strategies to improve nutrition and health security and pro-active public health approaches, it is important to understand and investigate the life style data indicators and mechanisms leading to malnutrition and the consequences in the study area. Thus, this thesis explored food insecurity and the health status of the Zanzibari population in Unguja, Tanzania and investigated the interconnected questions pivoting on household responses on access to food and individual impact on health and nutritional status of the population. Furthermore, the major emphasis will be on food (in) security and malnutrition and the root associations of the condition with cardio-metabolic risk factors and low-grade inflammation including all members of the household.

1.1 Research Background

1.1.1 Food Insecurity

During the World Food Summit in 2009, the Food and Agricultural Organization (FAO) defined food security as follows: "Food security exists when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2009).

In addition, the aim of the second sustainable development goal (SDG) is to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture"

For decades, Food and Agriculture Organization of the United Nations (FAO) has used the prevalence of undernourishment as an indicator to estimate hunger in the world. The trend of hunger in the world had a steady decline over the last decades but reverted in 2015 and remained unchanged till 2018 [24],where about 821 million people in the world suffered from hunger, emphasizing the immense challenge of achieving the Sustainable development Goal 2 (Zero Hunger) target by 2030 [24].

According to the World Health Organization (WHO) news release in July 2020, the hunger situation is envisaged to worsen due to the current COVID-19 pandemic situation which has been estimated to affect 130 million more people by the end of 2020 [25], this also setback the achievement goal of Zero Hunger by 2030. "Food insecurity"—the immediate cause of hunger [1] refers to limited access to food, at the level of individuals or households, due to lack of money or other resources. The severity of food insecurity is measured by Food Insecurity Experience Scale (FIES) [26] a tool used to monitor hunger.

According to the recent report of the state of food security and nutrition [24], about 2 billion people in the world experience some form of food insecurity, of which 750 million people are severely food insecure [24] and about 8% of the population in Northern America and Europe experience moderate food insecurity with uncertainties about access to adequate and nutritious food [24], putting them at a greater risk for various forms of malnutrition and poor health.

The world population is growing rapidly and expected to increase by 2.5 billion between 2007 and 2050, with most of the growth foreseen to occur in urban areas of developing countries[27]. This rapid growth and urbanization are expected to increase poverty and negatively impact the food security environment of urban dwellers, leading to food insecurity and malnutrition[20]. While the prevalence of food insecurity has been reducing in other parts of developing countries

Africa remains the region with the highest prevalence of severe food insecurity with an increase of about 18% in 2014 to 21% in 2018 [24]. Conflicts, economic shocks and climate shocks remain the key drivers of food insecurity in Africa [28].

During the last decade, Tanzania experienced a large economic growth but still experience a high degree of food insecurity on regional, district and household level [29] with 26% of the population not able to afford basic consumption needs and 8% experiencing extreme poverty [30]. This confirms, that food security at national level does not guarantee security at household level.

[1] It is important to note that "hunger" and "food insecurity" are distinct concepts. Whereas food insecurity refers to lack of regular access to enough safe and nutritious food while hunger is "an uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy." (Food and Agriculture Organization, FAO).

Tanzania is largely dependent on agriculture for employment which contributes about 28% of the country's GDP[31], about 74% of the rural Tanzanians engage in Agriculture [31] and its related activities as contributors of their livelihoods.

Access to food in Zanzibar is one of the foremost food security problems for many Zanzibari households both rural and urban. According to the Integrated Food Security Phase Classification (IPC) food and nutrition analysis report [32], 14% of the Zanzibari population surveyed are food insecure mostly requiring immediate food assistance e.g. the Northern district was among the districts with the highest prevalence of food insecurity [32].

There exist several studies in developing countries especially in Africa [33-36] that have investigated determinants of either household food security or food consumption behaviour in households. However, this is the first study in Zanzibar to investigate both their household food security situation and food consumption status. My publication aimed to describe food consumption and the food security status of Zanzibari households and to identify the socio-economic status and demographic correlates of food consumption and food security.

1.1.2 Health and Nutritional status

Malnutrition

The World Health organization defines malnutrition as "*deficiencies, excesses, or imbalances in a person's intake of energy and/or nutrients and addresses 3 conditions namely, undernutrition which includes wasting (low weight-for-height), stunting (low-height-for-age) and underweight (low weight-for age), micronutrients-related malnutrition which includes micronutrients deficiencies or micronutrient excess and overweight, obesity and diet –related non-communicable diseases (such as heart disease, stroke, diabetes and some cancers)*" WHO 2020.

Globally, there are 149 million children under 5 years who are stunted, 49 million children under five years are wasted [7]. Overweight and obesity continues to increase globally especially in school-age children and adults. Malnutrition and all forms are a global problem, and continue to be a public health issue in low-and-middle income countries. It was estimated that about 40 million children under five years were overweight [7] and in 2016 overweight in children between 5-9 years, adolescents and adults rounded to over 2 billion of which 44% of the children between 5-9 were obese [7].

Also, about 20-50% of the Sub-Saharan African urban population are either overweight or obese [21]. Even though there have been a reduction of stunting and wasting globally, Tanzania among other developing countries including Asia still suffers the most. Approximately, 3 million Tanzanian children under 5 years are stunted precisely, almost half a million being moderately acute malnourished and about 90,000 severely acute malnourished [22].

Most of the household income in Tanzania is spent in food purchase, yet malnutrition rate is high[29]. The high malnutrition rate has been contributed by poor knowledge of food preparations which included overcooking thus losing most of food nutrients in the process and also poor combination of food consumed in order to have a balanced diet[37]. The stunting rates in Zanzibar were ranging between 20% and 23% in Stone town and Unguja North respectively [22].

In Zanzibar, the prevalence of underweight in both sex in the age group 25-44 years was reported to be 8%, the prevalence of underweight in women was slightly higher than the male participants (8.9% vs. 7%) [23]. Also reported in the Tanzania National Nutrition survey [11], the prevalence of underweight in women of child bearing age between 15-49 years was 7.% , and just above 10% was reported in the Northern Unguja Island. The highest prevalence (14.8%) of underweight was observed in adolescents and adults between 15-19 years [11].

Furthermore, Tanzania is also facing the double burden of malnutrition, with the effects of over nutrition –including overweight and obesity. The prevalence of overweight and obesity have been reported to be higher in urban dwellers compared to rural communities. A study conducted in Dar-es-Salaam reported even higher prevalence of overweight (34.8%) and obesity (32.4%) which was partly associated with high soft drink consumption, fast food, alcohol consumption and hypertension [38]. Overweight and obesity have been reported to be more prevalent in female than male[9, 39, 40] , according to Tanzania Demographic Household Survey (TDHS) 2015/2016 about 28% of reproductive age women were overweight and obese of which about 39% were Zanzibari women[41].

In my first publication I investigated and reported nutrition status and proportions of underweight, overweight and obese individuals in different age groups and gender. The data collected is useful for health policy makers, educators and other stakeholders in planning effective and appropriate intervention programs targeting not only the vulnerable group (children, pregnant women, women, and elderly), but also the entire household in order to have an overview of the distribution of resources and recognize the potential risk factors timely.

Cardio Metabolic Risk

Globally, CVDs and the metabolic syndrome are the major causes of sudden death; CVDs and diabetes account for one-third of all death annually. [42]CVD is emerging as a significant health problem in sub-Saharan countries such as Tanzania. About 1.2 million deaths in Africa are attributed to CVDs and are expected to double by 2030[42]. The high burden of NCDs risk factors such as CVDs and diabetes are on the rise, in 2010 the prevalence of diabetes in Africa was estimated to be 3.8% and these numbers are expected to rise by 2030[43].

Overweight and obesity have been identified to be modifiable risk factors for cardio-metabolic and other chronic diseases [43] including hypertension [44], diabetes [45] and dyslipidaemia [46].As reported from the Ministry of Health (MOH), in Tanzania hyperglycaemic disorders was estimated to be around 20% in 2012[5] and hypertension was estimated to be around 26%[6].

Previous research [47, 48] reported that both total body fat and adipose tissue distribution were associated with cardio-metabolic risk. Previous studies from sub-Saharan African countries described high prevalence's of obesity and cardio-metabolic risk factors in adults in rural and urban areas [43]. However, there is still a dearth of population-based studies in sub-Saharan Africa investigating these associations with multiple cardio-metabolic risk factors and different obesity indices including percentage body fat, e.g. in both Tanzania mainland and Zanzibar Island.

In this publication [9] I reported the prevalence of overweight and obesity as measure by Body mass Index (BMI), the proportions of abdominal fat distribution and body fat percent in children and adults from 5 years. Furthermore, the proportion of cardiometabolic risks factors and its variation in different age groups. Additionally, the publication evaluated the independent associations of BMI, WC and percentage body fat with major CVD risk factors including (hypertension, total cholesterol, triglycerides, HDL, low-density lipoprotein (LDL), glycated haemoglobin (HbA1c), fasting plasma glucose and homeostasis model assessment of insulin resistance (HOMA-IR)).

Additionally, the publication by Brackmann et al.[49] which I co-authored investigated the proportion of hypertension in different age-groups including young children from 2 years old and determined it's possible correlates. Due to high prevalence of overweight/obesity and hypertension in the study area as reported in my publication [9, 50] and the fact that the survey was conducted in a coastal area of Unguja Island, evidence shows that people living in coastal areas rely on groundwater as their primary water source [51]; and most of coastal areas have been affected by seawater intrusion which increases groundwater salinity[52]. Drinking saline water has been reported to be associated with high blood pressure, preeclampsia and high sodium intake [52]. Other studies [51, 53, 54]have reported the association between dietary salt intake and hypertension, and that moderate reduction of dietary salt intake could effectively reduce blood pressure.

The publication [49] included about 1229 participants from 2-95 years and investigated the associations between anthropometric and urinary excretion of sodium and potassium as measured in morning spot urine on fasting status and blood pressure.

The results from both publications will serve as baseline data for developing and evaluating cost effective interventions, which could be used to curb the rising burden of NCDs. Additionally, the results are useful in developing policy measures for the prevention and surveillance of NCDs.

Inflammation

Obesity, along with diabetes, has recently been characterised by a state of chronic low-grade inflammation [55] and is characterised by excessive or abnormal body fat in the adipose tissue. Adipose tissues stores triglycerides and produces adipokines by acting as an endocrine organ [56], which plays an important role in controlling appetite, lipid metabolism and insulin resistance [57].

In individuals with obesity, adipocytes are enlarged and their secretory profiles are altered [58], they produce hormones such as leptin and generate increased amounts of pro-inflammatory cytokines, which among others include interleukin-6 (IL-6) and tumour necrosis factor (TNF-α) [59]. Together they stimulate the production of C-reactive protein (CRP) that is generated in the liver [60].

Furthermore, higher levels of inflammatory biomarkers CRP, IL-6 and TNF-α were reported to have been associated with increased glycated haemoglobin (HbA1c) as a marker for type 2 diabetes mellitus [61]. In turn, obesity measured using different indices, such as waist circumference (WC) and Body Mass Index (BMI) were associated with higher serum CRP levels and TNF-α [57, 62].

The publication [50] investigate the association between obesity indices and inflammatory markers (including CRP, IL-6, TNF-α) due to elevated leptin levels. Very few studies in sub-Saharan Africa have investigated the association of leptin and inflammatory markers with obesity indices[63, 64] and none of them explicitly investigated the role of obesity in low-grade inflammation in a Zanzibari population, whose obesity prevalence and the associated comorbidities have increased over the years.[23] .

My publication contributes to the general understanding on the association between obesity, leptin and low-grade inflammation in the sub-Saharan-African population. However, molecular studies are needed to explain this association in similar context as well as large population studies investigating the association between similar and additional biomarkers to add up to the scarce literature in sub-Saharan Africa.

1.2 Situation analysis and justification

According to Tanzania Nutrition and Food Centre (TNFC) report [65], nutrition works in Tanzania started since 1920s and the first surveys were conducted in Kilwa, Kilimanjaro and Arusha to assess nutrition status of the people specifically maternal and child health. Since then, Tanzania has made efforts towards addressing malnutrition by implementing public nutrition interventions and projects [66], and to date there are many intervention programs implemented by the government to attain food security as a means to protect the population against malnutrition [67].

However, there has been a slow progress in the reduction of malnutrition especially underweight in children, overweight/obesity in adults, reduction of cardiometabolic risk factors especially diabetes and hypertension and food insecurity. Key sectors i.e. education, agriculture, health, environment, community development, livestock and natural resources have to work together to complement direct interventions and address the underlying causes of malnutrition and its risk factors as well as ensuring feasible measures to be taken to reduce food insecurity from regional up to individual level.

A number of sectors have developed strategies and policies including Food and Nutrition Policy (1992) [68], Community Development Policy (1996), Child Development Policy (1996)[69], National Agriculture Policy (drafted in 2013), Water Policy (2002), National Livestock Policy (2006) and National Health Policy (1990)[70] (also discussed by Dominicus, DA. And Akamatsu, T. [71]) in order to improve the health of people by ensuring adequate intake of nutritious food and reduction of infectious diseases. However, data from mainland Tanzania show an increasing prevalence of overweight and obesity in urban, peri-urban, and rural areas [7-9]. Furthermore, about 14% of household in Zanzibar have severe food insecurity requiring immediate food assistance [32] while other parts of Zanzibar are insecure by lacking major sources of food. [72].

Access to clean water and improved sanitation is still a problem in Tanzania, about 27% of Zanzibari households have no or use unimproved toilet facilities[11].

In Zanzibar, education, food production, globalization, and sedentary lifestyle have noticeable effects on the health and nutrition status of the people. However, these data on nutrition and lifestyle factors and related determinants are scarce, my publication [9] adds up to the literature on the association of obesity with higher risk for hypertension, dyslipidaemia and type 2 diabetes mellitus in the Zanzibari population. Furthermore, my publication adds important information for the development of overweight/obesity prevention interventions promoting healthy diets and healthy lifestyles that will consequently help to reduce cardiovascular risk in the study population.

In addition, to understand why Zanzibari households are food insecure or have poor food consumption and some individuals are malnourished, my research approach [19] attempts to bring understanding and investigated the interplay of food access and social-demographic correlates on community and household level by developing and applying successfully a composite Food Access Score.

Additionally, my publication [50] investigated the role of obesity in low-grade inflammation on individual level in the Zanzibari population; very few studies in sub-Saharan Africa have conducted such investigations [63, 64] and none of them explicitly investigated the role of obesity in low-grade inflammation in a Zanzibari population, whose obesity prevalence and the associated comorbidities have increased over the years[23].

1.3 Topics of the thesis

Food insecurity

Publication 2: **Food insecurity, food consumption and food access**; presented the results on socio-demographic factors and the impact on food security and food consumption in the Zanzibari households, also highlighted the proportion of the population with moderate and severe food insecurity and poor food consumption. It includes a thorough discussion on the issue of food (in) security, food consumption and food access at household level and on the relevance of research and the objectives, my publication hopes in achieving.

The focus of my research was mostly on availability and accessibility of food in households and the ability of the household to provide adequate food for the needs of all members living under the same roof. Furthermore, how food is being distributed in the entire household, it was also import to understand and learn the way of living in such a community where polygamy was very common. The survey gives an overview of family structure and how other socio-demographic factors affects food situation in households.

In this publication, I developed a Food Access (FA) composite score, which was computed using selected variables, related to food accessibility and described more in the methodology part below. More information on suggested means on what households should do to ensure access to sufficient foods and economic/social coping mechanisms to help them in seasonal stress was also investigated and further discussed in my publication [19].

Health and Nutritional status

Publication 1: Prevalence of malnutrition; presents the proportion of the population with malnutrition indicators (underweight, overweight and obesity) within the 80 randomly selected Shehias and put the research in context. The background information puts the aims and main objectives of the research into a proper perspective, describing thoroughly the recruitment process and approaches, standardization, quality control measures, and data collection, with special attention to the design, responses, and participant characteristics of the overall project.

The data collection tools specifically anthropometric measurements described in my publication [40] have proven their potential as useful tools in the identification of proportion of the population with malnutrition thus trends observed were further utilised to formulate further publications, which could also be useful in development of other similar studies in sub-Saharan Africa.

Publication 3: obesity indices and cardio-metabolic risk factors; highlighted prevalence of multiple obesity indices (Body Mass Index (BMI), waist circumference (WC) and percentage body fat (%BF)) and cardio-metabolic risk factors and explored their association in the Zanzibar population in Unguja. My publication [9] is the first to ever report data on these associations in Zanzibar and the first to use bioelectrical impedance to estimate percentage body fat in remote and peri-urban communities.

My publication identified easy and efficient anthropometric measurements that could be included in routine screening for identification of population at risk especially in resource scarce areas like Zanzibar.

Publication 4: Obesity indices, leptin and inflammatory markers; investigated the association between obesity markers (Body Mass Index (BMI), waist circumference (WC) and percentage body fat (%BF)), leptin and inflammatory markers (C-reactive protein (CRP); Interleukin-6 (IL-6) and tumour-necrosis factor-α (TNF-α)) in a Zanzibari population which has not been reported previously in this population.

My publication [50] gave an overview on the role of obesity as a low-grade inflammation in the Unguja population. Furthermore, the results add up to the scarce literature in Sub-Saharan Africa on the association between adiposity, leptin and of low-grade inflammation and give an insight of these association in different age groups, from pre-school children and adolescents between 5-18 years, adults 18-45 years to participants above 45 years.

Publication 5: Anthropometric and Biochemical Predictors for Hypertension; this publication [49] extensively reported the prevalence of hypertension in the study population from children above 2 years, making it the first epidemiological research to ever report the prevalence of hypertension in children and also investigated the associations between markers of overweight/obesity and salt intake measured in morning spot urine and hypertension in Unguja Zanzibar.

I co-authored in this research approach in order to shed more light on the general understanding of hypertension and that it does not only affect adults but also children as young as 2 years. In addition, continued elevated blood pressure at young age can cause significant problems later on in life such as severe cardiovascular outcomes, thus the research recommends early screening and frequent monitoring in the study population.

Furthermore, the publication gives more details on biochemical sample collection of morning spot urine and the urinary excretion of sodium and potassium, which were used as surrogates for assessing salt intake used to investigate associations with blood pressure. The publication describes the usefulness of the results and how health professionals and physicians should use it as a starting point to educate patients on the importance of self-health care and importance of weight maintenance to prevent weight-related health risks.

1.4 Conceptual framework

To investigate the nutrition, health and food security situation in the study area, the project protocol was based on the United Nations Children's Fund (UNICEF) framework of the causes of malnutrition developed in 1990 as part of UNICEF's nutrition strategy and was adapted for the purpose of this dissertation. The UNICEF conceptual framework of malnutrition illustrates the multisectoral nature of nutrition problems [73] embracing food, health and care practices, which are proximal determinants of nutritional status. The framework has been used at national to household level as a guide in planning effective actions, assessing and analysing the causes of nutrition problem and identifies the appropriate actions to tackle the issue at each level.

According to UNICEF, the framework is classified into different causes i.e. immediate, underlying and basic causes, which are explained in three levels; individual, household and societal level respectively, factors at one level influence other factors (UNICEF, 1998).

The basic causes of malnutrition are explained as the potential resources available, in terms of environment, technology and people and the utilizations of such resources are limited by politics, culture, religion and economic- and social systems (UNICEF, 1998) which lead to poverty.

The underlying causes of malnutrition include insufficient access to food, inadequate maternal childcare, and inadequate health services, and poor living conditions e.g. poor water quality and sanitation cause infectious diseases such as diarrhoea or foodborne diseases. Insufficient access to food refers to financial, social and physical accessibility of food, which contribute to household food insecurity (UNICEF, 1998).

The immediate determinants of child's nutritional status are the dietary intake and health status of the child. Dietary intake and health status affect individuals directly and are influenced by household food insecurity (UNICEF, 1998).

In the current project the focus is on underlying and immediate causes of malnutrition, the framework served as a guide in developing the assessment tools used in the project e.g. household questionnaire, which was used in identifying the determinants of household food insecurity, investigated the living conditions and availability of sanitation and water facilities.

In the context of this thesis the UNICEF framework guides the following key subjects: Immediate causes: nutrition and health status affect individuals directly and are influenced by household food insecurity. My publication [19] assessed the household food (in) security situation using the Food Insecurity Experience Scale tool [26] and the relationship with food access and social demographic the correlates.

Unhealthy household environment, which in this case poor water quality and poor sanitation that were assessed in the household questionnaire as potential determinants of nutritional status. Also captured in the UNICEF framework in the context of poor sanitation is the increased vulnerability to diseases through malnutrition-infection vicious cycle. However, in this thesis, unhealthy household environment was used to report the proportions of households in the study population with improved/unimproved water and sanitation facilities, further research is envisaged.

Poverty and lack of income are the underlying causes of malnutrition. In addition, basic causes of malnutrition are caused by poor economic situation combined with environmental factors such as geographical region and are mostly on community, regional and/or national level. The theses explored the causes of malnutrition in 5 publications listed in the annex.

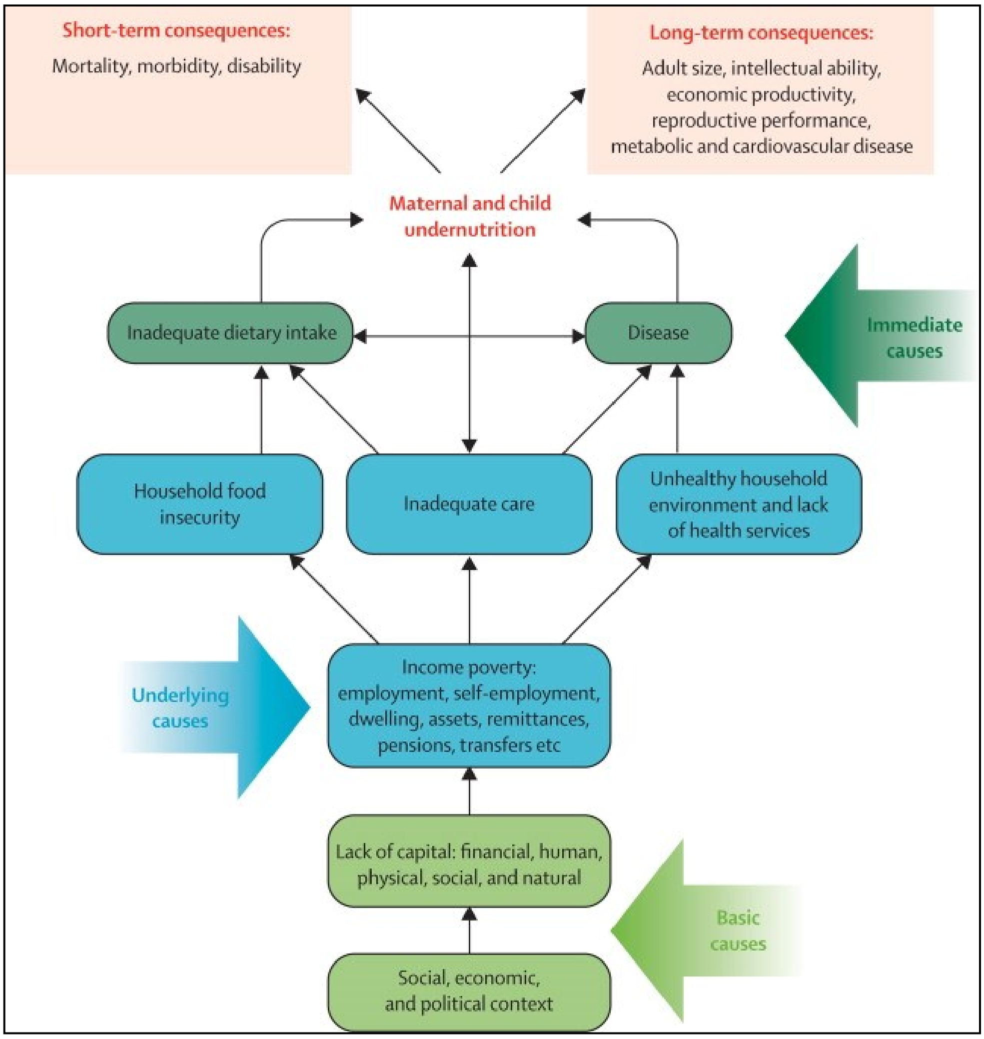

Figure 1: UNICEF Conceptual Framework on the causes of Malnutrition;

Adapted from (UNICEF, 1998) SOURCE: Lancet, 2008)

2 Objectives and Research Questions

2.1. Research objectives

The aim of the thesis was to investigate and understand potential role of socio- demographic and environmental factors of food access, food insecurity and food consumption and the implications for health, nutrition and inflammatory response in a Zanzibari population. Data analysis made use of cross-sectional data collected in 2013, including all members of the household. In addition, I developed a food access composite score including selected variables, related to food accessibility on household level.

To achieve and fulfil the main goal of the theses, the project examined

1. The prevalence of malnutrition in all age groups and determine anthropometric parameters for BMI z-score and body composition of all members of the selected household
2. whether an association exists between socio- demographic correlates (exposure), acceptable food consumption and food security (outcomes) and whether food access strengthened this association in the study population;
3. to determine the prevalence of obesity indices and cardiometabolic risk factors and their association
4. the association between markers of obesity in association with inflammatory markers, in particular CRP, IL6, IL8, TNF-α and Leptin;
5. the proportion of hypertension among Zanzibari of different age-groups and to detect its possible correlates

2.2. Research question

This cumulative thesis answered some of the gaps addressed in the following research questions:

a) What is the prevalence of malnutrition in the study population? (Publication 1)
    a. How was the data collected, who was eligible and why?
    b. Is the prevalence of malnutrition age- or gender specific?
    c. Which data collection tools are feasible in resource poor? In addition, how to reach a high response rate.

b) How does the interaction of food access with socio-demographic factors of the household have impact on household food (in) security and food consumption in the study population? (Publication 2)
    a. Is food access a better determinant for food insecurity and/or food consumption?

   b. Does the interaction of food access with socio-demographic factors strengthen the association with food insecurity and/or food consumption?
   c. Which policies and programs are to be implemented in order to address the problem of food insecurity and poor food consumption in the study area?

c) Are there any age group-specific differences in the association between body mass index (BMI), waist-circumference (WC) and percentage body fat (%BF) and cardio-metabolic risk factors? (Publication 3)
   a. Which cardio-metabolic risk factor is most prevalent in the study population?
   b. Is the prevalence of cardio-metabolic risk factors gender-, age-, and educational level- and area-specific?
   c. Which obesity indicator predicts cardio-metabolic disease in the study population best?

d) Is BMI, WC and %BF independently associated with leptin and inflammatory markers? (manuscript 4)
   a. How were the samples collected and who was included and why?
   b. Which of the obesity indices is a better predictor for leptin and the surveyed inflammatory markers?
   c. What is the role of obesity in low-grade inflammation?

3 Materials and Methods

This section explains the methodological design of the survey and how it was implemented, the usage and conceptualization of the project methodology in assessing food insecurity and health and nutrition status. In order to give a holistic methodology of the thesis, this section integrated the methods used in the individual manuscripts focusing on the project design and recruitments, data collection and data quality and management. More details of these topics are presented in the individual manuscripts.

3.1. Study design and recruitment

This is among the first cross-sectional studies conducted in Unguja Island that enrolled the entire household and sought to map health and nutrition outcome in the entire Island. This cross-sectional study included 80 randomly selected Shehia (wards) across Unguja Island. The survey was conducted in 2013 during the short rainy season (October-December).

Prior to project begin

A debriefing meeting with our partner in Zanzibar was held in July 2013 at the State University of Zanzibar (SUZA) Vuga Campus, for general introduction of the survey purpose and procedures, and to consult with the Ministry of Agriculture under department of food and nutrition in Zanzibar and UNICEF regarding the project protocol and to include measurement of important indicators not yet considered.

Project team recruitment

Recruitment of the project team (Master students, study nurse, laboratory technicians and drivers) was held in July in Zanzibar. Two Master students from SUZA (a male and a female), four laboratory technicians (two males from Mnazi mmoja Hospital, one male from Amana Hospital and a female laboratory assistant from SUZA), a female Nurse (from Muhimbili Hospital in Dar es Salaam) and two male drivers completed the field team.

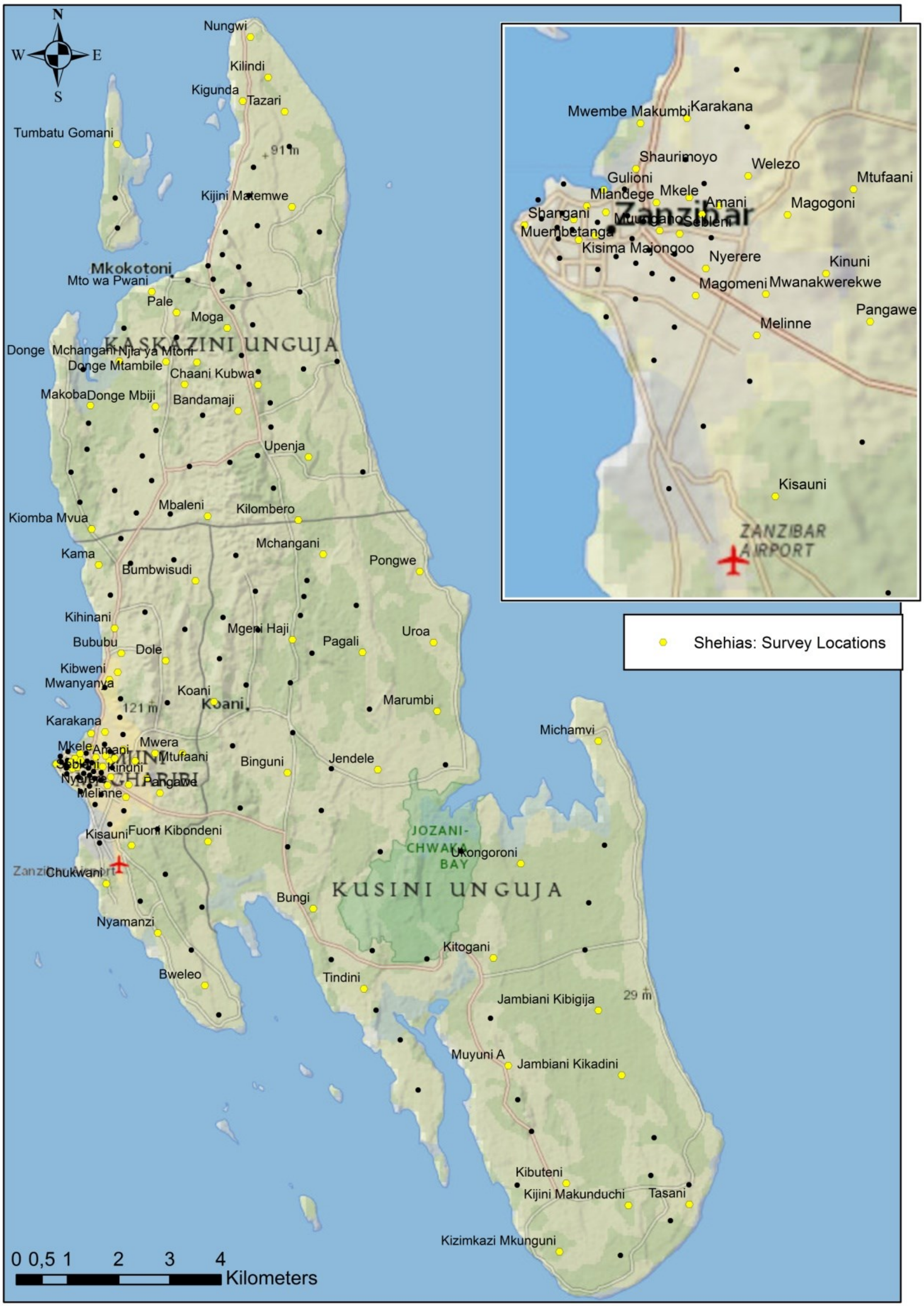

Figure 2: Survey points mapping of Shehias (yellow) where the survey was conducted,

SOURCE: BIPS

Study team training

In adherence to BIPS internal standards for research and quality control purposes, the project PhD student Maria Nyangasa and field supervisor attended comprehensive training on anthropometric and blood pressure measurements, which was conducted in Bremen by a member of the fieldwork department from BIPS. Further, blood drawing and urine sampling was trained together with laboratory standard operating procedures. Also, additional training in methods of field editing, data quality control procedures, and fieldwork documentation and coordination.

From the 9th-11th September 2013, local fieldwork training was conducted in Unguja with all the project team members following BIPS procedures and training manuals. The training lasted for 3 days, which included field practice in interviews and handling questionnaires, anthropometry, blood pressure measurements as well as bio-sample collection, processing and storage for the laboratory technicians.

Pre-testing

All data collection tools were pretested prior to the survey in a convenient sample. Two families took part in the pre-test in one of the Shehias in Unguja that were not included in the final sample of Shehias included in the overall project. Amendments were made on the questionnaires and the field routine where needed. Data collection practice commenced immediately after the pre-test and lasted from 16th September to 10th December 2013.

Shehia Selection

A two-staged cluster sampling technique was used; first stage involved the selection of Shehias from a list of 213 of all registered Shehias in Unguja Island from the *Tanzania population and housing Census 2010* list [74]. Eighty Shehias were randomly selected using a Statistical Software (SAS 9.3) procedure PROC SURVEYSELCT.

Household selection

The survey was designed to be a representative at the community and household level. Households were defined as a group that shared meals and slept under the same roof [75], all members in a household constituted the target population.

A second stage cluster sampling involved the selection of households from the 80 selected Shehias. Participating households were randomly selected within each Shehia through the official Sheha's registration (book) where all members of each Shehia were registered according to household number and/or street or zones number/name.

Meeting with the Shehas

Meeting invitations were sent to 80 Shehas of the selected Shehias. Meeting was held on the 12^{th} September 2013, at Bwawani hotel in Unguja and attended by 80 Shehas, district commissioners, our local representative who is also a Professor at the State University of Zanzibar Prof.Dr. Mohammed Sheikh, a Professor and co-investigator from the University of Bremen Prof.Dr. Sörge Kelm, the main investigator and the project leader Dr. Antje Hebestreit from BIPS in Bremen, Germany. The agenda of the meeting was to introduce the project aims and protocol, as well as to invite feedback from the Shehas on how to facilitate household enrolment and contact with the eligible families in order to increase willingness to participate.

Data collection and filed visits

Field visits were conducted twice a day. The first visit was scheduled in the evenings to reach the participating households: the field team together with the Sheha visited the selected households to inform about the survey aims and objectives, enrolment, and that participation in the project was voluntary, and the consent could be withdrawn at any time without specifying any reason.

On this visit, each household was provided with a Swahili informed consent form to read more about the survey before the examinations were conducted during the morning of the next day. In order to prepare documentation forms and assign an anonym number to each participant, a pre-documentation of all members of the households was made which included name of the Shehia, house number/zone name, family name (of the head of household), first name of all participants, gender and age. All the pre-documented materials were discarded once all the examinations in each household were completed.

On the next day (the examination day), the field team first spoke with the head of household who gave a signed copy of the informed consents and answered questions related to the general household questionnaire.

All participants administered the individual questionnaire and information on breastfeeding was collected from young children < 2 years, The field team completed the anthropometric data sheet. Bio-samples including morning spot urine was collected from all members of the household and venous blood samples were only collected from participants > 5 years. Blood drawing and anthropometric measurements were carried out in fasting status.

In a sub-sample, accelerometers were distributed to eligible members (children between 5-16 years).

3.2. *Sample size of the project*

The overall aim of the project was to estimate the prevalence of malnutrition in the Zanzibari population including possible determinants. The sample size calculation was based on predicted prevalence of chronic malnutrition of children under 5 years in Zanzibar (30%) [76], confidence interval of 95%, and a precision of +/-5%. Thus, sample size was estimated to be 1453 participants from 323 households, assuming that each household has 1 child > 5 years and each Shehia was to recruit 4 households.

However, the reality in the field was different from what was reported by the TDHS 2010 [77], the average number of household members in the study area was higher than reported, thus the number of households (323) was not reached as estimated in the initial study sample calculation. Even though only 239 households participated in the survey, one of the key points of the survey was to collect complete data from the entire household members and this was accomplished.

The overall inclusion criteria for the project were complete data on age, gender, weight and height/length in order to be able to estimate the malnutrition proportion of the overall population.

Sample size included in the individual publications is listed below with additional inclusion criteria for each publication corresponding to the main objectives of the publication.

Table 1 : Sample size of the population as used in each publication

Sample size of the population as used in each publication

No.	Publication Title	Publication Aim	Sample size
I	Design, Response Rates, and Population Characteristics of a Cross-Sectional Study in Zanzibar, Tanzania	To Provide a descriptive overview of recruitment approaches, standardization, quality control measures, and data collection, with special attention to the design, responses, and participant characteristics of the overall project.	239 households and 1314 individuals (newborns-95 years)

II	Exploring Food Access and Sociodemographic Correlates of Food Consumption and Food Insecurity in Zanzibari Households	To Explore the relationship between food access and sociodemographic correlates with food consumption score and food insecurity experience scale	196 Households
III	Association between cardiometabolic risk factors and body mass index, waist circumferences and percentage body fat in a Zanzibari cross-sectional study	To determine the prevalence of obesity indices and cardiometabolic risk factors and further investigate their association	470 participants above 5 years
IV	The association between leptin and inflammatory markers with obesity indices in Zanzibari children, adolescents, and adults	To investigate whether obesity contributed to low-grade inflammation in the study population	587 participants above 5 years
V	Anthropometric and Biochemical Predictors for Hypertension in a Cross-Sectional Study in Zanzibar, Tanzania	To investigate associations between objectively measured anthropometric and biochemical markers such as urinary sodium and potassium excretion from morning spot urine and blood pressure in different age groups.	235 households and 1,229 individuals (2 to 95 years)
*	*A sub-sample (publication in progress)*	*To measure objectively physical activity levels (average minutes per day).*	*102 children and adolescents of age between 3 and 16*

3.3. *Data collection tools/methods*

3.3.1. Questionnaires

Overall, the project included 3 questionnaires including, head of household questionnaire, household members' questionnaires, and young children below 2 years questionnaire which was used to assess food insecurity, food consumption, individual dietary diversity score, young children (under 2 years) feeding behaviours, socio-economic and socio-demographic status. Below Table 2 describes each questionnaire and the corresponding age group used for each questionnaire.

Head of household questionnaire

A partly validated head of household questionnaire was administered to the head of the household/household proxy and collected data on social, demographic and economic indicators of the household including ownership of livestock and assets, hygiene and sanitation, as well as information on household dietary behaviour including consumption and expenditure.

The questionnaire also included Swahili-translated versions of Food Insecurity Experience questions[78] adapted from the original FAO 2007[79] and Food Consumption Score [80]

In the case of polygamous families, all wives and their household members were also eligible for participation regardless of area of residence. Further, in the case of mixed/extended families, the head of the household was considered as the main correspondent unless the other members living in the same household had their own kitchen and independently taking care of their meals.

Food insecurity Experience Scale

Food insecurity was assessed using Food Insecurity Experience Scale, a standardised set of questions developed by the FAO [81] and administered to the head of household. The tool has been applied in a large number of countries following a standardised procedure. The tool's strength is its ability to capture experience and severity of household heads regarding food security of their households, which could not be captured by other tools. The key issues assessed in this tool were; components of uncertainty and worry about food, inadequate food quality and insufficient food quantity.

The method categorises households using a known food security experience scale, which measures the degree of food insecurity/hunger experienced by households in the last 12 months during the survey period. The response reported from 8 questions administered to the head of household is what determined the experience scale of the households. Mild, moderate and severe (hunger) are the 3 categories used by FAO [81] to define level of food insecurity/hunger.

Food Consumption Score

Food Consumption Score (FCS) was measured using a validated instrument [80, 82]. This is used to reflect the quality and quantity of food consumed in the household by applying a weighing system. FCS is a composite score based on dietary diversity, food frequency and relative nutritional importance of different food groups.

FCS captures information on both dietary diversity and food frequency (number of days food is consumed per week) and applies a weighting system [80]. The types of food groups included staples, pulses, fruits, vegetables, meat & fish, dairies, sugar, oil&fat, condiments. The United Nations World Food Program (WFP) established cut-off points to classifying FCS, FCS $\geq$ 21 was categorised as "poor", FCS=21.5-35.0 as "borderline" and FCS $\leq$ 35 as "acceptable" [83].

Food Access

An important component of food consumption and food insecurity included in the analysis was food access. In my publication, food access was defined as the ability of a household to acquire adequate amount of food through mixed strategies. Multiple indicators for food access were assessed, each representing a certain aspect of food access and derived variables were combined to a composite score.

The derived variables included (a) food source; main source of food consumed during the last seven days (b) food purchased; types of food frequently bought from shop/market during the last seven days, (c) own food; types of foods acquired from household production, and (d) market distance; distance to the nearest market/shop. All these variables were essential in computing the food access score, which was used in assessing the determinants of food insecurity, and food consumption score.

Individual Dietary Diversity Score

At Individual level, FAO assessed food consumption data using the Individual Dietary Diversity Score (IDDS) a tool based on 14-food groups adapted [79, 84]. In this survey IDDS was used to reflect the quality and mostly information on nutrients intake. IDDS tool is a simple qualitative tool that has been in large surveys to assess (micro) nutrient adequacy of diets by a simple count of food groups consumed in the last 24 hrs. [79, 84]. This tool has been validated and used in large surveys and is considered as a good proxy indicator for prediction of macro-and micronutrient adequacy of diets.

Furthermore, this tool provides information on the food consumed and food groups, type of nutrients, types of food consumed and nutrients. IDDS was assessed at individual level in order to identify vulnerable individuals in households with nutrients deficiency in their diets as well as used as a confounder in the determination of nutrition and health status.

Household member's questionnaire

Household member's questionnaire included two questionnaires, for members below 2 years and for all members above 2 years.

The questionnaire for young children below 2 years was administered to mothers/care taker and assessed dietary diversity and consumption frequency addressing in particular breastfeeding habits, weaning and a 24 hr. recall with food frequency questionnaire adapted from the World Health Organization (WHO)[85] .

The questionnaire for household members above 2 years was administered directly to all members above 16 years and mothers/caretakers answered for the children and adolescents below 16 years. The questionnaire collected demographic, social and economic data of each participant. To measure nutritional quality and micronutrients adequacy of individual's diets, Individual Dietary Diversity Score was calculated based on 14 food groups as recommended by FAO (2007) [79].

Table 2 : Target population groups and measurements in the questionnaires

Population groups	Measurements
Head of household	Household identification, household demography, household assets and livestock ownership, market distance, household food production, household food consumption and expenditure, sanitation and hygiene, food insecurity experience scale, food consumption score
Members of the household (2 years and above)	Demographic data, individual dietary diversity score, anthropometric measurements, blood pressure, pregnancy status, venous blood collection and urine sample
Infants (0-24 months)	Demographic data, breastfeeding, complementary feeding, anthropometric measurements

3.3.2. Anthropometric measurements

The survey covered standardised procedures for anthropometric measurements as recommended by the International Society for the Advanced of Kinanthropometry (ISAK) and physical examination [86, 87]. The ISAK protocol for anthropometry is recognised as the international standard for anthropometric measurement thus adaption of such a protocol is necessary to reduce measurement errors and allow comparison of studies in similar context.

The use of appropriate, validated and standardised equipment in collecting anthropometric data is important to minimize measurement errors. In this publication body weight and body composition (bio-electrical impedance and %BF) were measured in fasting status using an electronic scale (TANITA BC-420 SMA, Germany) which has been used for epidemiological studies.

In accordance with ISAK [87], standing height that is used in calculating the body mass index (BMI) was measured using a stadiometer (Seca 213 Stadiometer, UK) attached to a wall so that participants are vertically aligned. Also, recumbent length of young children under 2y and those who could not yet stand alone was measured using a measuring board (Seca 417 measuring board, UK) placed horizontally on a flat surface; all measurements taken were recorded to the nearest 0.1 cm and were further used in calculating BMI

Body mass index (BMI) was calculated as kilogram per square m (kg/m^2); and to account for differences in BMI for children and adolescents, age-specific and sex-specific Z-scores and percentiles were calculated according to WHO centile curves [88, 89] which were defined as overweight (BMI between >75th and <95th percentile) and obesity (BMI>95th percentile) categories. For adults, overweight/obesity was defined as BMI ≥25kg/m2 as recommended by WHO [90] .

High % BF was defined as ≥85th percentile for boys and girls below 18 years according to McCarthy et al.[91], while high %BF for adults was defined as ≥20% for men and≥32% for women [92]. Waist circumference (WC) was measured on standing position using an inelastic measuring tape (SECA 201) to the nearest 0.1cm. Waist circumference was measured at midway between the lower rib margin and the iliac crest. High abdominal obesity was defined as (waist circumference ≥90th percentile) for children below 10 years [93], waist circumference ≥90th percentile for adolescents below 16 years and waist circumference >94 cm for men and > 80 cm for women for participants above 16 years as recommended by IDF [94].

Due to cultural and religious reasons, all measurements were taken on light clothing and could not be taken directly on bare skin especially when measurements were to be taken from an opposite sex. The complete description of the anthropometric measurements of the study have been described here [40].

3.3.3. Bio-samples

Cardiometabolic parameters were assessed through venous blood samples, which were collected from all members above 5 years on an overnight fasting status. Collection, processing and storage of blood samples are described here [40].

This participated population has a wide range of age group (0-96 years) for both genders, thus different cardiometabolic risk definitions and cut-offs were used in corresponding to each age-sex specification as indicated in table 3.

Cardio-metabolic risk for children between 5-10 years was defined according to age- and sex-specific cut-offs including hypertension (Systolic Blood Pressure (SBP) and diastolic blood pressure (DBP)), blood lipids (high total cholesterol (TC), high triglycerides (TG), low-density-lipoprotein cholesterol (LDL-C) and high-density-lipoprotein cholesterol (HDL-C)) and blood glucose/insulin (Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) and elevated fasting plasma glucose (FPG) were defined according to the IDEFICS Study [93, 95] and glycated haemoglobin (HbA1c) was defined according to Rodoo et al. [96] for children under 17 years.

For children, adolescence and adults from 10 years and above, hypertension was defined according to age- and sex-specific cut-offs as recommended [97] this cut-off was used for children between 10 and 18 years only and for adult above 18 years hypertension was defined as recommended [98].

Blood lipids (TC and LDL-C) were defined according to National Cholesterol Education Program (NCEP) [99] and TG, HDL-C and FPG were defined according to International Diabetes Federation (IDF) [94]. HbA1c for adults above 17 years was defined according to Stern et al. [100] and insulin resistance was estimated as HOMA-IR according to reference value of HOMA-IR as recommended by Shashaj et al. [101].

In my publication, 75th percentile cut-off was used for children and adolescents from 10 till 17 years and for participants above 17 years, HOMA-IR was defined according to von Eyben et al [102] and calculated from glucose (mmol/l)) and insulin (µU/ml) concentrations using the formula: HOMA-IR=(fasting insulin×fasting glucose/22.5)[103].

Table 3 : Cardio-metabolic risk definitions and references

Age group	Obesity Indices and Blood Pressure	Blood lipids	Blood Glucose/Insulin
Children: ≤10y	BMI ≥75th percentile [1]	TC ≥90th percentile [2]	HbA1c ≥ 97.5th percentile[10]
	WC ≥90th percentile [2]	TG ≥90th percentile [2]	HOMA-IR ≥ 95th percentile [2]
	BF %≥85th percentile [3]	HDL-C ≤ 10th percentile [2]	FPG ≥ 95th percentile [2]
	SBP≥90th centile or DBP ≥90th centile [2]	LDL ≥90th percentile [2]	
Adolescents: >10 to	BMI ≥ 75th percentile [1]	TC ≥5.2 mmol/L [6]	HbA1c ≥ 97.5th percentile[10]

<16 y	WC ≥90th percentile [4]	TG ≥1.7mmol/L [4]	HOMA-IR ≥75th percentile [9]
	BF %≥85th percentile [3]	HDL-C < 1.03 [4]	FPG ≥ 5.6mmol/L [4]
	SBP≥140mmHg or DBP≥90mmHg [11]	LDL ≥3.4mmol/L [6]	
Adults: ≥16y	BMI ≥ 25 kg/m^2 [1]	TC ≥5.2 mmol/l [6]	HbA1c ≥ 6.1% [5]
	WC ≥ 94 cm male, ≥80cm female [4]	TG ≥1.7mmol/L,[4]	HOMA-IR >4.65 or HOMA-IR >3.60 and BMI >27.5 kg/m^2 [7]
	BF % ≥ 20 male and ≥32 female [8]	HDL-C < 1.03 male, < 1.29 female [4]	FPG ≥ 5.6mmol/L[4]
	SBP≥140mmHg or DBP≥90mmHg [12]	LDL ≥3.4mmol/L [6]	

1. WHO 2. IDEFICS Study 3. McCarthy, H.D., et al. (2006) 4. IDF 5. Stern, S.E., et al (2003) for adults above 17 years 6. NCEP 7. von Eyben, F.E., et al (2005) 8. Gallagher, D., et al (200)
9 Shashaj et al. (2015) for children and adolescence under 17 years 10. Rodoo P et al. (2013)
11, 12 National Institute of Health 3rd and 7th report respectively

Analysis of total cholesterol (TC), high-density lipoprotein (HDL), triglycerides (TG) and Fasting glucose and insulin were analysed at the Mnazi Mmoja hospital laboratory in Zanzibar by trained master students as well as at the University Bremen by a trained laboratory technician according to the same standard procedures.

3.4. *Methods of data analysis*

To address the aim of each publication, different statistical modelling approaches were employed. In addition to descriptive statistics, linear-, Poisson-, and logistic regression models including multilevel logistic and multinomial logistic regression models were used. Summary of the variables used in the publications are indicated on table 4 this section gives a summary of the analysis for each publication.

Table 4 : Socio-demographic and socio-economic correlates and their measures as used in publications

Variable name	Variable description	Measure

Age group	Age was grouped into three categories: children and adolescents, adults and older participants	≥5 to <18 years ≥18 to <45 years 45+ years
Age groups *	Age was grouped in to four categories: young children, children, young adults and adults	2 to ≤9 years >9 to ≤ 19 years >19 to ≤ 40 years >40 years
Area of residence	Information on region, district and Shehia (the smallest administrative unit in Zanzibar) was recorded to determine area of residence of the head of household. Urban and peri-urban were merged into one category "urban".	Urban=1; rural=0
IDDS	Individual Dietary Diversity Score (IDDS) was calculated based on the 14-food groups classification recommended by Food and Agriculture Organization (FAO) [79] and included as confounder. Two categories were then developed according to the median; low and high	low ≤4; high >4
Education	Highest education level attained by the head of household as identified ISCED[104]. Low education level (primary school and below) and high education level (secondary school and above).	High=1; low=0
FA	A composite score for FA was computed as the mean of the values of the derived variables multiplied by 4 (number of all derived variables). The FA-score ranged from 4–8, and FA was then categorised as "poor food access" (≤6)	Poor=1; good=0
FCS	Food consumption Score	Poor =1; acceptable= 0
FIES	Food insecurity experience scale	Insecure=1; Secure = 0
Gender	Gender of the head of household	Male=1; female=2
Household size	Average number of household members in each household. Household with more than six (6) members were considered as a big family "large".	Large=1; small=0
Marital status	Marital status of the head of household. Type of marriage was considered; either married in polygamous or monogamous or not married (single, widow, cohabitation, divorced).	Married=1; not married=0
Number of jobs	Numbers of jobs of the head of household, multiple occupations were also considered.	One or more=1; no job =0
Number of vehicles	Number of transportations means owned by any member of the household from a list of 5 items, two categories were used; at least one type of vehicle and no vehicle.	at least one type of vehicle" =1; none=0

Wealth	To assess wealth of the households, the median number of animals and assets in the households was calculated; two categories were used, wealthy and poor.	wealthy ≥5); poor<5

* Age categories as used in Brackmann et al.[49]

3.4.1. Correlates of food insecurity and food consumption

As major correlates of food insecurity and food consumption, the present thesis collected this information as means of questionnaires administered to the head of household (HH).

First, the publication identified the proportion food insecure households and those having poor food consumption; also, as an important component of food insecurity and food consumption, my publication identified households with poor food access. Secondly, my publication investigated the socio-demographic characteristics that are correlated with food insecurity and poor food consumption. In light of this, the hypothesis that, those HH characteristics, the household characteristics and food access have relative importance in determining the status of household food insecurity and food consumption.

In order to test the hypothesis, the associations between the exposure variables (socio-demographic and food access) with either food consumption score or food insecurity experience scale as outcome variables were explored. The dependent variable in this case is a dummy variable, which takes a value of zero or one depending on whether or not the household experiences food insecurity or has poor food consumption.

The transformation of these variables followed the categorisation of two distinct groups, thus, linear-, Poisson-, and logistic regression models were evaluated and used with regard to model fit and Pearson residuals as well as Quantile-Quantile (Q–Q) plots. For the Poisson regression analysis, food security, mild and moderate food insecurity was dichotomised into "mild to moderate" (0) and "severe food insecurity" (1) and poor consumption and borderline were dichotomised into "poor" (0) and "acceptable" (1).

Multilevel logistic regression models were specified to identify the correlates of food insecurity and food consumption and to assess their importance in determining the likeliness of being food insecure and/or having poor food consumption status at household level. Multilevel logistic regression models calculated the odds ratios (OR) and 95% confidence limits (CI) and accounted for clustering within Shehia level using a random intercept. Furthermore, statistical interactions between each correlate and food access (correlate*FA) were investigated. Hence, the predictive power of each socioeconomic and demographic factor with FA on Food Consumption Score and food insecurity experience scale was tested separately.

Each model was again adjusted for the remaining correlates, including a random intercept for the Shehia level.

3.4.2. The association between obesity indices and cardio metabolic risk factors

In order to investigate the proportions of the obesity indices (including overweight/obesity, high waist circumference and high percentage body fat) and cardio-metabolic risk factors as well as determining their association, data on anthropometry and cardio-metabolic risk factors were collected.

Covariates data (age, gender education level, and occupation, number of jobs and area of residence) and dietary assessment (individual dietary diversity score) were collected though a questionnaire. Descriptive analysis of the participants' characteristics including covariates, obesity indices and the cardiometabolic risk parameters was provided. Calculated mean and standard deviations (SD), ranges and distribution of the categorical data in N and percentages (%) were also reported for this publication analysis.

The association between obesity indices and cardiometabolic risk factors was analysed using mixed logistic regression models based on the GLIMMIX procedure. First, mixed logistic regression models were conducted to estimate the association between each of the three obesity indicators (BMI, waist circumference and percentage body fat as exposure variables and each of the eight risk factors (hypertension, TC, TG, HDL-C, LDL-C, HbA1c, FPG and HOMA-IR) as dependent variables, in terms of ORs and 95%CIs.

Since BMI, waist circumference and percentage body fat are inter-related; the strongest relationship with cardiometabolic risk factors was investigated by conducting mixed logistic regression models. This was done by estimating the association (ORs and 95% CIs) between all three obesity indices as dependent variables in one model and each of the eight risk factors as outcome variables.

All models were adjusted for potential confounders and covariates such as gender, age, and education level according to International Standard Classification of Education (ISCED)[104], area of residence and utilization of hypertension medication.

3.4.3. Anthropometric and Biochemical predictors for Hypertension in a cross-sectional Study in Zanzibar, Tanzania

Descriptive statistics including mean and standard deviation (SD) for continuous variables, frequency (N) and proportions (%) for categorical variables were used to give a summary of the sample collected stratified by age-group. Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA)

Hypertension in this publication was categorised into hypertensive/ pre-hypertensive and normal blood pressure. For the investigation of the association between the markers of weight status (BMI, BF % and WC) and biochemical markers (urinary excretion: sodium, potassium, creatinine and sodium-to-potassium ratio) with hypertension, a multilevel logistic regression was applied using GLIMMIX procedure.

In each regression model, quartiles of BMI, WC, BF% and 24h sodium-to-potassium ration were included as independent variables. Since educational level was reported to be significantly correlated with age in children, therefore, the highest education level in the household for all participants ≤ 19 years considered as the adjustment variable in the regression models. All models were adjusted for age, sex and area of residence and stratified by age-groups.

3.4.4. The association between leptin and inflammatory markers with obesity indices

Both descriptive and analytical statistics were used. The statistical techniques and methods used are outlined in details in the publication [9]. Statistical analysis was performed using SAS V.9.3 (SAS Institute, Cary, North Carolina, USA); statistical significance was set at α=0.05.

Descriptive statistics (mean, standard deviations, median, interquartile range) were used to summarize the data. Analytical statistics were used to investigate the association between the predictor variables (obesity indices) and outcome variables (quartiles of leptin and inflammatory markers).

Association of obesity indices (BMI, waist circumference and %BF) with quartiles of leptin, CRP, IL6, TNF-α and levels were modelled by multinomial logistic regression analysis based on the LOGISTIC procedure that accounted for ordinal outcome variables with four categories (Q1-Q4) with Q1 as the reference variable.

A regression analysis was conducted in two steps: first, 12 models including each of the four inflammatory markers with each of the three obesity indices was modelled. Secondly, Since BMI, WC and %BF are interrelated, their predictive power on inflammatory markers and Leptin were investigated in a regression model considering all obesity indices against each of the outcome variables. Thus, four models including each leptin and inflammatory marker with all the three obesity indices combined in one model.

Since age and sex are reported to be significantly associated with leptin and some of the inflammatory markers thus included in the multinomial regression models as an adjustment variable; other confounders and covariates adjusted in the models include education level area of residence and utilization of hypertension medication.

3.5. Ethical and data protection

Prior to data collection, it was mandatory to submit a copy of the research protocol to ethical committees in Zanzibar and Bremen who made sure that the research is grounded on scientific and ethical standards. This is especially important in developing countries and resource scare settings where there are higher proportions of vulnerable people due to poverty and illiteracy [50] who are unaware of their rights.

This project adhered to all ethical principles in collecting the data, majority of the participants agreed to participate after being well informed in Swahili about the aim of the project, the benefits and all examinations conducted including blood drawing for those eligible and willing to

Besides the verbal information given, all participants older than 16 years gave written consent and parents/guardians gave written consent on behalf of their children younger than 16 years before any examinations were conducted. Participants signed two copies of the consent form, whereby one remained with them and the second is kept locked up in Bremen.

The ethical committees of the Ethics Committees of the University of Bremen and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee provided ethical approval; the project was conducted in accordance with the ethical standards laid down in the Declaration of Helsinki and its later amendments.

3.6. Data quality and data management

All measurements and methods followed standard operation procedures and were adopted from the IDEFICS study [87, 95] All field members attended three-day training and pre-testing of field procedures and measures prior the start of the survey. In order to decrease measurement errors or discrepancies in this project, an inter- and intra-observer reliability measurement was assessed by repeated measurements of 4 anthropometric measurements (height/length, waist circumference, mid-upper-arm-circumference and hip circumference) on the same subject. The technical error of measurement (TEM), coefficient of reliability and intraclass correlation coefficient (ICC) were then calculated.

For measuring each of the 4 anthropometric measurements at least three consecutive times within 1 h measurements were carried out by each of the field members in 20 children (10 girls and 10 boys, al primary school) as proposed by the protocol of reliability measurements. Analysis was performed according to Stromfai et al [87].

In addition, in order to maximize comparability of data, this project used two teams in data collection; both teams used the same technical equipment and instruments. It was important that in each team a male and female study nurse was available to conduct sex-specific physiological and anthropometric measurements. In addition, there was a regular swapping of the field team members and quality control was applied daily during the field phase to increase data quality. All numerical variables were entered twice independently during data entry and inconstancies were eliminated where necessary.

Quality control during bio sample analysis comprised double analysis in most parameters where feasible (HbA1c, glucose, total cholesterol, triglycerides, LDL) and a third scan when the difference between the first two values was >10%. Other parameters were measured once, and reference samples (n=6) were scanned randomly in an independent laboratory in Germany (Labormedizin MVZ Dr. Eberhard & Partner) controlling for inter-assay reproducibility of values.

Interclass coefficient correlation (ICC) between the two sets was calculated for the measurements of Cholesterol, Glucose NaF, HbA1c, HDL-cholesterol, LDL-cholesterol, LDL-HDL-Quotient and Triglycerides.

4 Main findings and discussion

This chapter summarizes the key results pertaining to the objectives that guided this research project. These results have been described in more detail in the related manuscripts (see Annex I - VIII).

The main objective of this dissertation was to explore various aspects of food insecurity, nutrition and health status of the Zanzibari population in Unguja.

The purpose of the general discussion is to answer the research questions and give a short summary of the overall findings across the five publications, emphasizing on the key contributions of the findings and suggest possible way forward for future research in the targeted population or similar context.

4.1 Response rate and participants characteristics

<u>Responses</u>

Publication 1 provided the overall description of the survey, the response rate for each examination conducted and reported the proportions of the population with malnutrition.

The overall response rate of the surveyed population was 97.9% whereby 244 households and 1541 household members were contacted, even though the number of households contacted was less than what was estimated in the sample calculation, still the estimated number of participants was reached. This was achieved earlier than expected due to the high number of household members which was averagely 8 members per household almost twice as estimated and reported from the Tanzanian census [105]. However, about 86% (n=1314) of the contacted individuals from 239 households fulfilled the inclusion criteria (age, sex, length/height, weight) and were included as a complete sample for the analysis as used in different publications.

The non-response among selected households (5 households) was the refusal to participate which was officially (contacted the research team and gave back the inform consent forms) and unofficially (did not contact the research team and did not open the door for the research team on the day of the examination).

Ninety-eight individuals refused to participate and 129 did not fulfil the inclusion criteria. The refusal to participate were due to several reasons which some of the contacted participants shared with the research team, was the trust of sharing their information not being sure what the purpose was, even after the research team provided all the information. Very common also heard was the provision of blood and urine sample, which was associated with witchcraft and other, beliefs. Some of the participants refused blood draw due to fear of testing the blood for diseases such as HIV, this was also reported in Ghana [106, 107].

However, the high response proportion was a result of the benefit receiving a comprehensive Swahili feedback on the anthropometric measurements, body composition, blood pressure and urine dipstick test results (which was given out for feedback purposes only). Participating households further received freshly baked local bread for breakfast.

There were no repeated visits to the households where the members were not available during examination time.

Age-gender distribution

The exact date of birth of some of the reported participants was mostly taken from documents such as birth certificates, birth registration, vaccination cards and/or national identification cards. However, some of the participant's especially elderly participants could not recall their exact date of birth or did not have any documentation. This has also been reported during the 2012 Tanzania census [37] whereby, majority of the older population did not have birth certificate compared to the younger generation.

Birth date/year was then recorded with the help of a local event calendar, which was developed, during the survey training to assist the participants in recalling events that occurred during their birth. Event calendar has also been used to assist in age reporting in Tanzania [11] and by other researchers [108, 109]. Furthermore, Food and Agriculture Organization (FAO) [110]recommends the use of event calendar during data collection to reduce errors in estimating date of birth where no records are available.

The age-gender distribution shows that, the surveyed population is a young population which consisted of about 43% of children below the age of 15 years; of which 11% are under 5 years and about one-third (32%) are school age children between 5-15y and about 6% of individuals above 60 years. This pattern is similar to that reported in the Tanzanian Demographic Health Survey (TDHS) [76] with about 47% of the population being children under 15 years, which was a result due to high fertility in the past thus larger proportion of the population in Tanzania are younger children. This pattern is also similar to many other African countries with high fertility and mortality rate [37].

Similarly, slightly higher than that reported in the TDHS [76], more than half of the participants (54%) consisted of adults between 15-65years known as economically reproductive age group. However, the proportion of young male participants between 25-45 years were observed to be less than that of female, this could be due to migration especially "dago" where fishermen travel and camp away from their homes in search for fish [111, 112]. Fishing was a common activity in the study population and since this project was conducted between October-December, which is a season for greater catch when the sea is relatively calm with weaker currents [112], this could be the reason for such high proportion of female than male of age between 25-45 years in the surveyed population during the survey time.

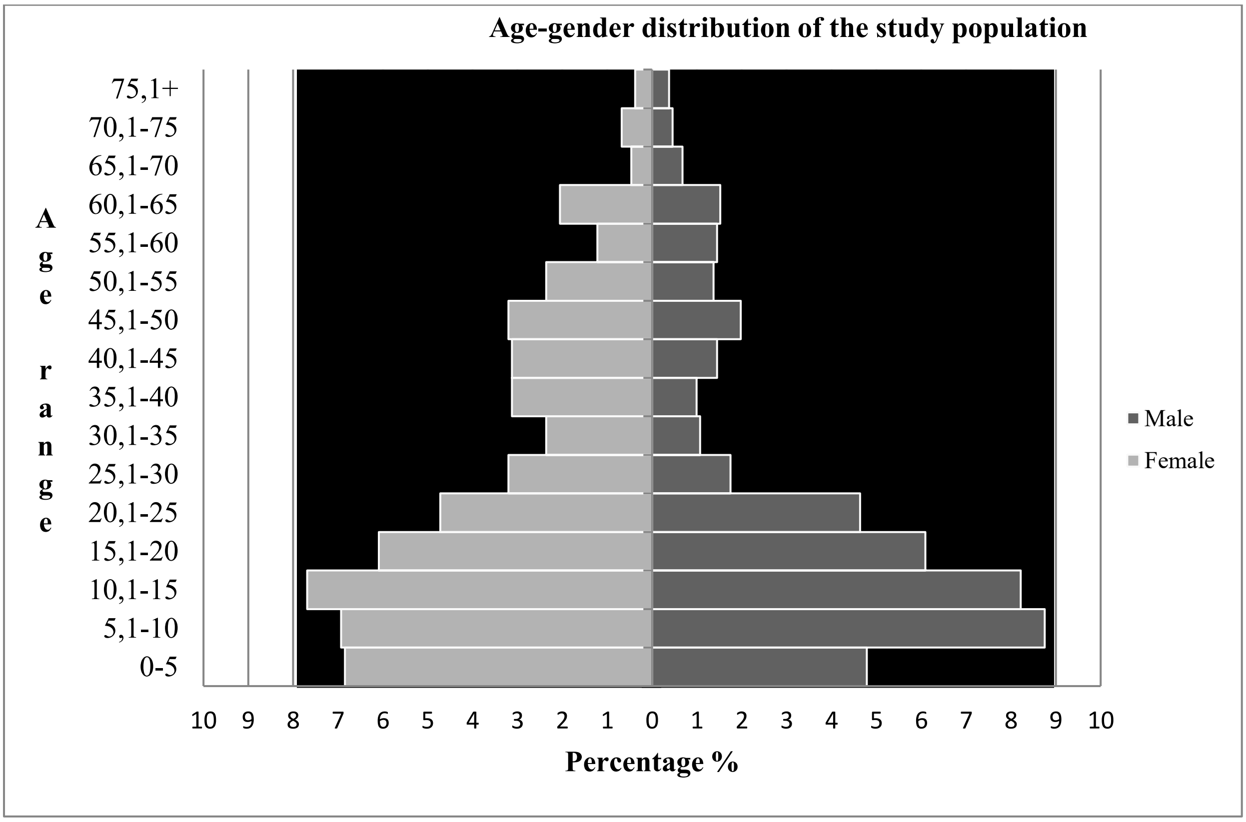

Figure 3: Age-gender study population pyramid; SOURCE: Nyangasa MA

4.2 Household characteristics

Household characteristics are important and can be used as a proxy measure of determinants of food security status, nutrition and health status of the household members. These characteristics can also be used as indicators of the socioeconomic and demographic status of the HH and the household, below are some of the household characteristics as reported and assesses in the HH questionnaire.

4.2.1 Household structure, household size

The TDHS [77] defined a ***household as a person or a group of persons, related or unrelated, who live together and share a common source of food and livelihood, and recognize one person as a***

head. The household characteristic comprised of general information of the household and socio-demographic characteristics of the HH. Understanding the general household characteristics of sampled households gives an overview of the general features prevailing in the study area and a snapshot of the household's welfare. Head of households are the main contributors to the livelihood of their households; thus, it is particularly important to investigate and determine their socio-demographic characteristics.

Consistence with the study area, the socio-demographic information showed that, men (63%) headed the majority of the surveyed households. More than half (55%) of the HH are in monogamy marriages; however, polygamy is still practiced in Zanzibar Island. Tanzania has been reported to be one of the few countries that still "officially" practice polygamy and other traditional polygamy in rural areas and that one in four women in Tanzania are in polygamy [113] similar to what has been reported in this publication with about 26% of the HH engaged in polygamous marriage.

Overcrowding of households was common in urban surveyed households with an average of 8.1 persons per household. Most households consisted of either member of the same family or extended family members, such as grandparents, uncles and aunties. Also, commonly practiced in Zanzibar is the rural-urban migration for search of better life, not every person that migrate succeeds in life, majority end up having no job and no better life and stay with family and friends in the urban areas adding more burden to the host. A study in Nigeria [36]confirmed that, large family size has a negative impact on household security.

In Sub-Saharan Africa, agriculture and livestock ownership has proven to play a major role as a source of food and nutrition security [114]. In this publication ownership of livestock and assets were considered to assess wealth of the household. Livestock keeping was fairly common, chicken were predominantly kept by about 50% of the surveyed households, also cows and goats were common. Respondents mentioned that milk production for family consumption and cash incomes from animal sales were the two major purposes of keeping livestock. Agriculture and livestock keeping continue to contribute to nutrition of the people, animal-source foods are a rich source of bioavailable nutrients that play an important role in reducing the risk of protein malnutrition [115].

Also, consumer goods/assets were also common in the area despite the low income, mobile phone was owned by majority of the households followed by radio, paraffin lamps and television. More than half of the households (68%) owned a bicycle and was used mostly as a means of transportation around the different communities. In the study area, wealth was associated with food insecurity, wealthy households had a lower chance of severe food insecurity (OR 0.52; 95% CI 0.25–1.11).

4.2.2 Water and sanitation

Approximately 1, 5 million deaths per year in children under the age of 5 years are caused by diarrhoea related to unsafe water, lack of basic sanitation and poor hygiene, most of them in developing countries [116, 117]. In Tanzania as reported in 2015, about 8% of death of children under five is due to diarrhoea resulted by poor access to improved and safe water and sanitation [115].

Access to safe water and poor sanitation conditions is still a problem in some communities in Zanzibar Island whereby, about 11% use unimproved sanitation facilities and 17% have no toilet facilities of any kind [41]. However, access to drinking water is no more a big problem in the Island the trend has been improving over the years, in 2016 only about 2% of the population used water from an unimproved water source, nevertheless, more than three-quarter of participated households' study did not have safe drinking water. Most of the households reported to consume water directly without any further treatment while about 16% reported to boil, bleach or leave the water on the sun for some few hours before consumption.

Treating water before drinking is important to help reduce waterborne and water-related diseases like diarrhoea and cholera even when fetched from a protected source like taps and covered wells. Diarrheal is caused mainly by the ingestion of pathogens especially found in unsafe drinking water, from unwashed hands or in contaminated food.

The lack of sanitation not only causes millions of deaths through diarrheal disease, but is also associated with poverty. Poor sanitation conditions and inadequate sanitation in this project was common in rural areas. Majority of the participants had toilet facilities and only about 8% did not have any type of toilet facility in their household. Lack of sanitation facilities in the households force the people to defecate/urinate openly in the fields around their homes. Thus, exposing them to faecal pathogen which has been reported to be associated with diarrhoea and other multiple infectious diseases like soil-transmitted helminth infection, schistosomiasis and trachoma [118, 119].

More than half of the participants, used unimproved toilet facilities especially pit latrines and about one-third of the population used flashed toilets. In the surveyed population, only about 4% of the participants with toilets had to share with other households while majority of the households had their own toilet in their premises without having to share with other households.

4.3 Food insecurity: Correlates of Food Consumption and Food Insecurity

Some of the Socio-demographic factors associated with food insecurity and poor food consumption are reported below. Polygamy has been associated with severe food insecurity in this population (OR 3.95; 95% CI 1.17–13.4); this is in line with previous findings from Tanzania mainland [120]. However other studies reported contrasting findings [121, 122], it was postulated that polygamous households contain more members which means greater chance of having more financial and labour support among the members thus increasing chance for food-security.

Nevertheless, overcrowding which was a major problem in the current population especially in the urban population has been associated with food insecurity, poverty and hunger. Also confirmed in this publication, larger households had a higher chance for severe food insecurity (OR 2.44; 95% CI 1.16–5.13) compared to households with fewer members simply because smaller households are easily manageable in terms of resources. This could also be due to the fact that the number of active members/contributors in the household is less than the dependent members (see distribution pyramid) who are mostly school children and adolescents. However, to estimate the exact effect of household size on food insecurity was challenging, as several other factors including number of members who actively contribute to the households needs including food and other necessary expenditures could not be verified in the data collection and analysis.

Nevertheless, food access was used as a mediator between socio-demographic correlates and food insecurity and food consumption to investigate further if its improved changes in the chances observed on the food insecurity and food consumption situation when interacted with socio-demographic factors. Results showed lower chance for severe food insecurity in households with higher-educated HH either with good food access (OR 0.42; 95% CI 0.15–1.17) or poor food access (OR 0.40; 95% CI 0.16; 1.02) and in households with lower-educated HH and good food access (OR 0.49; 95% CI 0.18–1.30). Furthermore, households having at least one vehicle tentatively increased the chance of having acceptable food consumption for both good and poor food access (OR 2.17; 95% CI 0.68–6.87; OR 1.83; 95% CI 0.59–5.71, respectively).

The results indicate that education level of the HH as well as FA both played a comparable role in influencing the food insecurity status of the household. And that even households without a vehicle had a higher chance of acceptable food consumption when they had good food access indicates the importance of other aspects of the food access —in addition to infrastructure—such as borrowing foods, receiving foods as a gift, and own food production or animal rearing. The interplay of multiple factors facilitating food accessibility should be considered in future intervention studies.

4.4 Health and Nutritional status

4.4.1 Nutritional status of the study population

Like in many other low-and-middle-income countries [13, 123, 124], the current population experiences a double burden of malnutrition characterised by the coexistence of underweight and overweight individuals in the same population. The trend of underweight was observed to increase with decreasing age group, whereby, male participates were more prevalent than female in all age groups. The trend of overweight was observed to increase with increasing age group and most prevalent in female adolescents and adults.

To answer the research question *„What is the prevalence of malnutrition in the study population? and "Is the prevalence of malnutrition age- or gender specific*" This project used anthropometric data in assessing individual's nutritional status, anthropometric data is useful in identifying children at increased risk of malnutrition, diseases and death. Slightly more than one-third (36.5%) of the participants were underweight and the prevalence of overweight and obesity in the population was 13% and 8.14% respectively.

Yes, the prevalence of malnutrition in the current population was age and gender-specific the prevalence increases with increasing age. The highest prevalence (73%) of underweight or being too thin for the age was observed in young children below 5 years which is higher (14%) than that reported by TDHS 2015/2016[41]. The prevalence of underweight in school age children between 5-14 years was 58%, young adults and adults between 15-59 years was 16.5% and about 14% of the elderly participants above 60 years were underweight.

In school age children between 5-15 years, similar trend observed as that of children below 5 years the underweight proportion in boys is also higher than that of girls and the overweight proportion was observed to be higher in girls compared to boys.

According the findings of my publication, adult females ages 15-59 years were more obese (18.39%) compared with males of the same age group. One-third (32.18%) of the elderly participants, both male and female and 60+ years, were overweight, and 16.09% were obese.

The high proportions of underweight in children in the surveyed population could be due to inadequate food intake due to lack of resources and poverty, also poor knowledge of food preparation and consumption of healthy diets. Mother's education level and household wealth status has been associated with poor nutritionals status in Tanzania, according to TDHS [41], the prevalence of underweight was highest among children in the lowest wealth quartile and the prevalence decreased with increasing mother's education level.

Similarly, the high prevalence of overweight and obesity in the current population could be due rural-urban migration which is common in Zanzibar especially for individuals between 25-50 years. Rural-urban migration has been associated with poor food choices and poor eating habits which and overweight/obesity especially in developing countries.

The high prevalence of overweight and obesity could also be due to sedentary lifestyle in urban areas especially women, even though physical activity was not assessed in the main project, but from the nature of the jobs and activities reported by urban dwellers there was very little to no physically demanding activities whereby about26% reported to be engaged in services and trade [40] in the contrary to majority of the rural dweller who reported to have more than one job and engaged mostly in agriculture, fishing and mining.

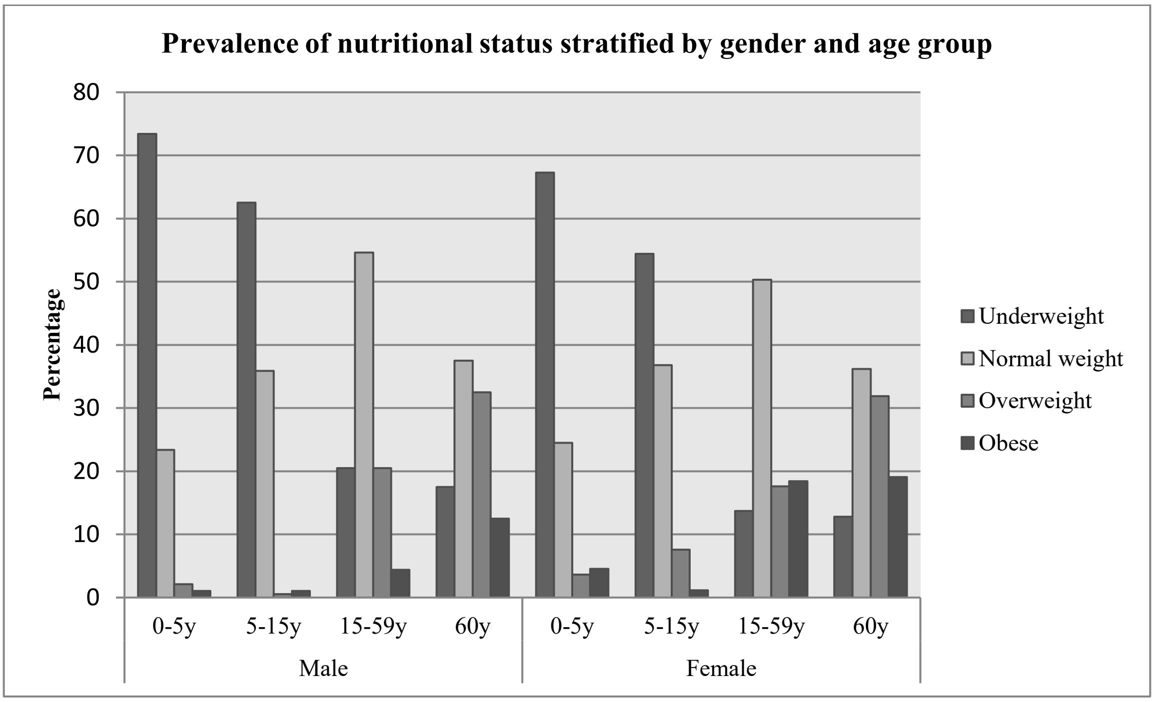

Figure 4: Prevalence of nutritional status stratified by gender and age-group; SOURCE. Nyangasa MA

4.4.2 Obesity indices and cardio metabolic risk factors

Among different anthropometric measures, several studies have focused on using BMI, which is widely acceptable and easily applicable measure of obesity in investigating the association with morbidity and mortality [125]. However, limitations have to be addressed, such as it does not distinguish between the distribution of adipose tissue and muscle [126] but it simply measures the ratio of weight in relation to height. Therefore, to overcome the limitations the international guidelines advocate for the use and routine measurement of waist circumference, percentage body fat and waist-to-hip ratio in the assessment of adiposity to predict the mortality risk [127]. Recently another anthropometric measurement A Body Shape Index (ABSI) that is based on waist circumference adjusted for height and weight appeared to be a substantial risk factor for premature death [128]. Also, reported in a large European cohort by Christakoudi et al.[129] that ABSI complements best BMI and achieve efficient mortality risk stratification in the BMI categories (underweight/obese and normal weight/overweight) compared to alternative indices of abdominal obesity.

In my publication 3 [9], I investigated the association between BMI, waist circumference and %BF with cardiometabolic risk factors for individuals above 5 years. Among the presented anthropometric measures, high waist circumference and high percentage body fat showed association with high levels of LDL-C (OR=2.52 (95% CI 1.24 to 5.13), OR=1.91 (95% CI 1.02 to 3.58), respectively). Additionally, BMI and waist circumference also showed association with high levels of HbA1c (OR=2.08 (95% CI 1.15 to 3.79), OR=3.01 (95% CI 1.51 to 6.03), respectively). (Table 5).

However, in the combined regression models (Table 6), waist circumference was associated with higher chance for hypertension (OR=2.62 (95% CI 1.14 to 6.06)) and for high levels of HbA1c (OR=2.62 (95% CI 1.12 to 6.15)). These findings suggest that even though all the three anthropometric measurements were associated with hypertension and also reported in other studies [43, 130], however the association with waist circumference was twice as strong compared to BMI and percentage body fat. This result suggests that central obesity may be a better indicator for the risk of hypertension and other cardio-vascular diseases in our current population, similar results have also been reported [48, 127, 131, 132]. Furthermore, a number of studies have reported that waist circumference predicted mortality risk better than BMI [39, 131-134] additionally, WHO suggested waist circumference to be used as an alternative to BMI in predicting disease risks [135].

Even though waist circumference has been a proven parameter optimal for the diagnosis of the metabolic syndrome, hypertension and cardiovascular risk factors, there are still questions whether the internationally proposed waist circumference cut-off is appropriate for Sub-Saharan African population. According to Katchunga, P.B. et al,[136] the waist circumference cut-off used for black African population may over predict abdominal fat excess in women, similarly, Crowther, N.J. et al [137] reported that 91.5cm is the optimal waist circumference cut-off for the diagnosis of metabolic syndrome in sub-Saharan African women and not 80cm as recommended. Nevertheless, more research is needed to provide adequate cut-offs in sub-Saharan African population.

Furthermore, publication 5 [49] reported high prevalence of hypertension especially in overweight or obese participants above 40 years. Additionally, results showed positive association between BMI and body composition in participants above 19 years. However, there was a negative association with salt intake in participants between 9 and 19 years.

Table 5 : Associations between obesity indices (independent) and cardiometabolic risk factors (dependent), adjusted for gender, age, education level, area of residence and hypertension medication (n=470)

Risk Factors [a]	High BMI				High WC				High BF%			
	OR	(95% CI)		AIC	OR	(95% CI)		AIC	OR	(95% CI)		AIC
Hypertension	**2.41**	**1.33**	**4.47**	**504.86**	**3.68**	**1.81**	**7.52**	**499.79**	**2.51**	**1.40**	**4.51**	**503.46**
High Total cholesterol	1.13	0.40	3.19	192.74	0.84	0.27	2.66	192.71	1.05	0.37	2.95	192.79
High Triglycerides	1.79	0.55	5.77	189.88	2.23	0.58	8.66	189.38	1.64	0.52	5.14	190.11
Low HDL cholesterol	1.21	0.62	2.37	516.08	1.15	0.55	2.42	516.25	1.06	0.54	2.05	516.37
High LDL cholesterol	1.45	0.78	2.69	457.62	**2.52**	**1.24**	**5.13**	**452.23**	**1.91**	**1.02**	**3.58**	**454.77**
High HbA1c	**2.08**	**1.15**	**3.79**	**442.70**	**3.01**	**1.51**	**6.03**	**438.53**	1.75	0.96	3.18	445.23
High Glucose	2.04	0.93	4.50	397.36	2.07	0.84	5.07	397.98	1.76	0.80	3.87	398.56

Table 6 : Association between combined obesity indices (exposure) and cardio-metabolic risk factors (outcome) adjusted by gender, age, education level and area of residence (n=470)

Risk Factors	Combined Obesity Indices									AIC total
	BMI			WC			BF%			
	OR	(95% CI)		OR	(95% CI)		OR	(95% CI)		
Hypertension	1.19	0.48	2.95	**2.62**	**1.1**	**6.06**	1.48	0.63	3.51	501.39
High Total cholesterol	1.31	0.25	6.79	0.71	0.1	2.92	1.01	0.19	5.32	196.50
High Triglycerides	1.34	0.25	7.16	1.90	0.3	9.52	1.02	0.19	5.52	193.20
Low HDL cholesterol	1.35	0.48	3.76	1.09	0.4	2.67	0.82	0.98	2.25	519.92
High LDL cholesterol	0.63	0.24	1.65	2.34	0.9	5.50	1.81	0.70	4.70	454.68
High HbA1c	1.53	0.61	3.81	**2.62**	**1.1**	**6.15**	0.82	0.32	2.10	441.66
Elevated Glucose	1.67	0.55	5.06	1.54	0.5	4.44	1.03	0.33	3.17	400.64

4.4.3 Obesity indices, Leptin and Inflammatory markers

In publication 4, an attempt was made to investigate possible associations between obesity indices including BMI, waist circumference and %BF and leptin and inflammatory markers such as CRP, IL-6, TNF-a. Overweight/obese participants showed elevated mean concentration for Leptin and CRP compared to underweight/normal weight participants (7.9 ± 5.9 ng/ml vs. 3.5 ± 4.7 ng/ml and 0.33

± 0.6 µg/ml vs. 0.14 ± 0.4 µg/ml, respectively). Elevated plasma levels of leptin and CRP have been reported in number of conditions including obesity and inflammation and have been linked to increased cardiovascular risks [138].

According to the results of my publication, quasi-linear association of single obesity indices with leptin and CRP reported that overweight/obese individuals had a higher chance of having the highest levels of leptin (Table 7) (fourth quartile, model 1a; OR = 73.02 [95% CI, 16.00; 333.2]) and CRP (fourth quartile, model 2a; OR = 5.25 [95 % CI, 2.57; 10.74]). However, these associations were not prominent for CRP quartiles when obesity indices were combined in one model in Table 8, except for participants with high % BF, who were significantly more likely to have higher CRP levels (third quartile, model 6; OR = 3.49 [95% CI, 1.31; 9.31]).

Adipocytes dysfunction—due to adipose expansion—may have local or systemic effects on inflammatory responses, which may then contribute to the initiation and progression of obesity-induced metabolic and cardiovascular risk factors, such as type 2 diabetes mellitus. High %BF in this population was associated with higher leptin and higher CRP concentrations, which have been closely linked to insulin resistance, a known risk factor for non-communicable disease.

Table 7 : Association between each inflammatory marker and leptin in terms of odds ratios (OR) and 95% confidence limits (95% CL) with each obesity index adjusted for age group, sex, education level of the head of household and area of residence (models 1-4; a-c)

Dependent variable: Leptin and Inflammatory markers Models	N	Quartiles	Weight Status (BMI) (overweight /obesity vs. normal weight) OR (95%) (a)	Waist Circumference (high vs. normal) OR (95%) (b)	Body fat % (high vs. normal) OR (95%) (c)
1. Leptin (N=440)	113	1st quartile	Ref	Ref	Ref
	112	2nd quartile	**7.73 (1.64; 36.45)**	1.90 (0.67; 5.17)	**5.80 (1.79; 18.75)**
	114	3rd quartile	**28.61 (6.38; 128.3)**	**7.73 (2.97; 20.11)**	**22.01 (6.97; 69.50)**
	101	4th quartile	**73.02 (16.00; 333.2)**	**21.55(7.99; 58.09)**	**87.19 (25.80; 294.7)**
2.CRP (N=482)	130	1st quartile	Ref	Ref	Ref
	126	2nd quartile	**2.31 (1.18; 4.55)**	1.92 (0.95; 3.89)	**2.27 (1.18; 6.44)**
	129	3rd quartile	**2.42 (1.23; 4.78)**	**2.30 (1.14; 4.62)**	**3.41 (1.77; 6.55)**
	97	4th quartile	**5.25 (2.57; 10.74)**	**4.03 (1.93; 8.45)**	**4.97 (2.46; 10.05)**

3. IL-6 (N=420)	114	1st quartile	Ref	Ref	Ref
	105	2nd quartile	0.72 (0.37; 1.41)	1.24 (0.60; 2.53)	0.95 (0.49; 1.83)
	107	3rd quartile	0.82 (0.43; 1.59)	1.38 (0.68; 2.81)	1.17 (0.61; 2.25)
	94	4th quartile	0.67 (0.34; 1.34)	0.96 (0.45; 2.04)	0.84 (0.42; 1.67)
4. TNF-α (N=408)	108	1st quartile	Ref	Ref	Ref
	105	2nd quartile	1.59 (0.81; 3.12)	1.19 (0.58; 2.47)	1.11 (0.57; 2.15)
	99	3rd quartile	1.26 (0.63; 2.53)	0.88 (0.42; 1.84)	0.92 (0.46; 1.82)
	96	4th quartile	0.92 (0.45; 1.87)	1.01 (0.48; 2.13)	0.86 (0.43; 1.71)

Table 8 : Association between inflammatory markers and leptin quartiles in terms of odds ratios (OR) and 95% confidence limits (95% CL) with all three obesity indices combined in one model adjusted age group, sex, education level of the head of household and area of residence models (models 5-8)

Dependent variable: Leptin and Inflammatory makers Models	N	Quartiles	Weight Status (BMI) (overweight /obesity vs. normal weight) OR (95%)	Waist Circumference (high vs. normal) OR (95%)	Body fat % (high vs. normal) OR (95%)
5. Leptin (N=440)	113	1st quartile	Ref	Ref	Ref
	112	2nd quartile	3.34 (0.54;20.60)	1.01 (0.33;3.07)	3.14 (0.78;12.71)
	114	3rd quartile	**5.75 (1.00;33.03)**	2.64 (0.90;7.70)	**6.24 (1.60;24.26)**
	101	4th quartile	**6.36 (1.09;37.12)**	**4.87 (1.59;14.94)**	**19.23 (4.70;78.66)**
6.CRP (N=482)	130	1st quartile	Ref	Ref	ref
	126	2nd quartile	1.49 (0.52;4.27)	1.20 (0.52; 2.78)	1.56 (0.56;4.29)
	129	3rd quartile	0.83 (0.29;2.32)	1.25 (0.54;2.88)	**3.49 (1.31;9.31)**
	97	4th quartile	2.33 (0.76;7.18)	1.72 (0.71;4.17)	2.02 (0.67;6.13)
7. IL-6 (N=420)	114	1st quartile	Ref	Ref	Ref
	105	2nd quartile	0.43 (0.14;1.32)	1.58 (0.67;3.74)	1.46 (0.48;4.45)
	107	3rd quartile	0.40 (0.14;1.19)	1.58 (0.67;3.73)	1.89 (0.64;5.6)
	94	4th quartile	0.50 (0.16;1.51)	1.20 (0.49;2.98)	1.34 (0.44;4.13)

8. TNF-α (N=408)	108	1st quartile	Ref	Ref	Ref
	105	2nd quartile	2.56 (0.85;7.68)	1.02 (0.42;2.47)	0.54 (0.18;1.62)
	99	3rd quartile	2.22 (0.71;6.95)	0.80 (0.32;1.96)	0.57 (0.18;1.77)
	96	4th quartile	1.02 (0.34;3.03)	1.16 (0.47;2.88)	0.79 (0.27;2.28)

5 Strength and limitations, prospective research direction and challenges

5.1 Strength and limitations

Even though this project was conducted during the short-rainy season which made it challenging to access to some parts of the Shehias, the project reached a high response rate and collected high quality data using standardised operating procedures and established, validated instruments. The high response rate was a result of transparency, a close cooperation and involvement of the Shehas facilitated an easy and problem-free enrolment of participants and data collection.

Additionally, the involvement of the local institution prior to the data collection was crucial to discuss on the relevance of the data for the community and the health and nutrition institutions, such as politicians, clinicians and NGOs. Thus, it is important to involve the local institutions and local leaders of the study area at all-time points.

Furthermore, the project recruited the entire household members and provided feedback results as incentives, which did not only motivate the participation, but also provided them with information on their health status immediately after the measurements and free of charge.

Despite the limitation of this project having collected cross-sectional data, as a result, the interpretation of the findings is limited to associations between the outcome and predictor variables and the effects of seasonal variations could not be investigated. Nevertheless, it provides important understanding of the food security situation, health and nutrition status of the study area.

Furthermore, although food insecurity experience scale; food consumption score and Individual Dietary Diversity Score are validated and robust assessment tools, there is still room for bias based on self-reporting thus social desirability could have influenced the responses given by the participants or proxies. However, to overcome these limitations, with the help of probing as described here [79] also Martin-Prevel et al. [139] suggested the use of qualitative free listing recalls.

Even though the survey participants were selected randomly and the selected Shehias due to poor road conditions and poor infrastructures, it was not possible to collect blood and urine samples from some of the remote areas, thus some biomarker analysis could not be investigated thus selection bias could not be excluded.

Furthermore, some of the assessment tools e.g. food consumption score, required participants to recall meals consumed in the last 7 days or the household food insecurity experience in the last 12 months this create room for recall bias and participants are more likely to under-report their consumption frequency [80]. Nonetheless the limitations, the results are generally consistent with theoretical and empirical literature.

5.2 *Prospective research direction*

The findings and the limitations associated with this project present opportunity for future research. The findings of my publications first, contribute to the literature of food insecurity, health and nutrition and have implications for policy makers on food security, health and nutrition in Unguja Island, and other developing countries.

For instance, the finding that food access confounds the association between food insecurity /food consumption and socio-demographic factors indicates the complexity of food and health in developing countries. Food insecurity and poor food consumption in a context of poor FA especially educational level and household size presents higher burden for the population in general. Additionally, facilitating households' FA and the interplay of multiple factors facilitating food accessibility should be considered in future intervention studies to improve the population's health and nutrition situation. Also, implementation of policies and programs in their agendas to address educational activities and different forms of practical coping strategies, such as efficient food storage techniques and home gardening.

Furthermore, in order to reveal causal associations between the outcome and predictor variables, it will be necessary to use longitudinal data. Causal relationship could model effect margins when policy is shifted around the variables. For example, results from longitudinal data analysis would be able to indicate the extent to which policy on food insecurity would impact on socio-demographic factors and food access as well as policy on health and nutrition and the impact on malnutrition which could be important for policy making.

Furthermore, future research could extend the examination of food insecurity, health and nutrition to other aspects of health. In this respect, the current project is an important addition to the literature. However, investigation between food insecurity and maternal care especially for household with young children or the association between food insecurity and nutritional status or general health would likely show more nuanced relationship and further develop the literature in the context of Unguja, particularly as already proven in the UNICEF framework of malnutrition and studies in other contexts have shown mixed results.

My publication findings reported alarming prevalence of overweight/obesity especially in women of child bearing age between 15-59 years, high hypertension and raised blood glucose besides a high prevalence of under-weight in children under 14 years, there is a need for locally-tailored approaches to increase awareness of overweight/obesity as a risk factor for CVD and other chronic diseases.

Further research is needed to investigate the association between leptin, inflammatory markers and dietary intake, research shows that healthy eating patterns including whole grains, vegetables and fruits and fish have been associated with lower inflammation [140]. Above all, to what extent high inflammation levels play a role in some of the cardiometabolic risk factors especially in overweight and obese individuals. Several studies have investigated the association between low-grade inflammation with hypertension [141, 142] and diabetes [143] and none in Tanzania or East Africa.

Due to high prevalence of hypertension among the participants, further analysis of the current population is planned to investigate the association between blood pressure and the quality (potassium and sodium) of the water sources used for drinking in the participated Shehias. Several studies mostly in coastal areas [51-54] have investigated and reported associations between blood pressure and drinking water salinity. The simple explanation given is that the problem of saline intrusion into drinking is likely to be exacerbated by climate change induced sea-level rise thus, putting the people at increased risk of hypertension and associated diseases[51, 52]. Our survey data are a source for further investigations and analysis; and provide a valuable starting point for future interventions.

5.3 Methodological consideration and challenges

Resource scarce communities like Unguja and many other communities in developing countries need efficient, cheap, simple and easy to use data collection tools, which will still yield valid and accurate results. This study used several validated tools in assessing individual and household dietary information including individual dietary diversity score, food consumption score, food insecurity experience scale and standardised tools in collecting anthropometric data and blood pressure data.

However, some of the tools used especially IDDS tool, has been used in several studies to collect data from e.g. children [144, 145], women [146], pregnant women, elderly in a household. My research is the first to use the IDDS tool and collect data from all members living in the household. Even though IDDS is a simple and straightforward tool it was a big challenge for parents to give information for their young children especially school age children under 16 years. Parents had to recall all meals consumed in the last 24hrs including those consumed outside their homes which was difficult for some children to recall. We had to probe the children and the parents to remember some of the single food items consumed starting from breakfast to dinner.

Due to the poor health system and high costs of medical consultation in Tanzania, which makes it difficult for people to do regular health check-ups, it was a challenge to collect medical history from participants. Some of the participants especially the elderly did not have any medical records and did not know of their health conditions. This was particularly clear when testing the morning spot urine using urine strips where several participants showed high sugar levels in their urine even on fasting status.

Additionally, blood pressure measurements of some of the participants showed elevated systolic blood pressure higher than 120mmHg and /or diastolic blood pressure higher than 80mmHg even after resting for 5 minutes and repeated the measurements, which majority of them did not know what the readings meant. As an incentive, we recorded all the results of the anthropometry, body composition, blood pressure and that of the Urine strips and handed over to all participants, and urged them to take the results and visit the next clinic or contact a doctor for further control.

Blood pressure measurements were collected for all members including young children from 2 years, this project is one of the first to collect such data in Zanzibar. It was a challenge to collect these measurements in young children due to their playfulness and instability. In addition, due to the poor conditions of some of the households, it was difficult to find a table or a convenient place where blood pressure measurements could be taken appropriately. These challenges were discussed during the field team training and discussed on how to overcome them. The field team and I travelled with metal boxes, which were used as material storage; this was sometimes improvised as tables in order to take blood pressure measurements according to the standard procedures as recommended.

One of the methodological challenges was taking anthropometric measurements from women and young children. Women wore several layers of light clothing during measurements, which might have affected the measurements taken. However, these challenges are unlikely to change the findings and prevalence in women and adults because 1 kg for clothing was deducted from weight measurements before weighing for all participants.

Another challenge encountered was that most of the participants did not know or could not remember their precise date, month, and/or year of birth; however, this problem was solved with the help of an event calendar developed by the field team prior to the fieldwork. The calendar described dates/month/year of important public events that occurred in the country (e.g. floods, war, elections, death of an important leader etc.) which helped some of the members to remember some important events that occurred during their birth or birth of their children. However, this issue of unregistered births is slowly getting solved as in 2016, it was reported that about 72% of children under 5 years had birth certificates and about 90% of the births were registered in Zanzibar [41].

Furthermore, as the questionnaires were extensive, in particular if the head of household questionnaire had to be completed with additional household member questionnaires, this might have created a response fatigue and thus influenced the completeness of the responses. However, this was solved by allowing small breaks in between every questionnaire, the respondents was then assigned to another examination apart from the questionnaire. Still, multiple HH questionnaires were not completed and thus some households could not be considered for the respective analysis, which has to be acknowledged as a limitation. Therefore, a final check for completeness of information before leaving the household is recommended to overcome this limitation.

Due to logistical reasons, not all bio-samples (urine and venous blood) were collected from all members. Since bio-samples were to be collected and processed on the same day and stored under 80°C, no bio-samples were collected in Shehias were the field team stayed overnight but data from other examinations was collected. This reduced the availability of biomarkers from mainly rural participants and hampered investigations associating anthropometric data with biomarkers. Thus, generalization of the respective findings was not possible.

6 Conclusion and further recommendations

This research project was driven by these-core topics; food insecurity, nutrition, and health, covering these topics involved incorporating and integrating research and data from broad areas-health, lifestyle data, anthropometric data, livestock and assets, to name just a few.

Based on my findings, poor access to food may be seen as a modifiable factor for food consumption and perceived food insecurity in Zanzibari households, in particular for the association with educational level and household size. To improve food and nutrition security in Zanzibar, implementation of policies and programs that address education activities and different forms of practical coping strategies, such as efficient food storage techniques and home gardening, in their agendas are needed, particularly in rural areas. In parallel, strategies should consider improvement of infrastructure to facilitate distribution of produce within the rural–urban areas, as well as education campaigns on food quality and utilization, emphasizing on the importance of food group and balanced diets.

Additionally, findings from my thesis provide insight into determinants of cardiometabolic profile in children, adolescents, adults and elderly participants, thus supporting the evidence that development of cardiometabolic risk starts early in life if not well controlled. However, based on results, I recommend repeating the examination longitudinally including children, adolescents, adults and elderly in similar context, as done currently in the COVID-19 in ZNZ project. My publication also reported high proportion of children and adolescents to be at risk for diabetes and /or pre-diabetes, thus recommended for better screening the use of the cut-off of HbA1c at ≥6.1 % and/or elevated fasting glucose at ≥5.6 mmol/L in order to identify those at risk earlier. Also, highly recommended, is the use of %BF and waist circumference in addition to BMI for screening and monitoring for dyslipidaemia and hypertension.

The findings from this project reported that poor access to food might be seen as a modifiable factor for food consumption and perceived food insecurity in the surveyed population particularly the association with head of household educational level and household size. The findings add up to the knowledge and inform the development of interventions strategies and policies aiming at improving food consumption and food security in Zanzibar. Furthermore, this thesis highlights the importance of adiposity, as a risk factor in itself, and for cardiovascular and cardiometabolic risk. The results of my thesis add important information for the development of obesity prevention interventions promoting healthy diets and healthy lifestyles that will consequently help to reduce cardiovascular risk in this current population.

6.1 Further recommendations

Based on the findings of my publications, below are possible recommendations that could be made from this project:

- For policy makers, as results of my thesis confirmed positive and significant association between household size and food insecurity, attention has to be given to limit increasing population in the project area especially in the urban areas were the average household size was eight members per household. This could be achieved by creating sufficient awareness and educate the people about effective family planning. Also, create more opportunities that will be beneficial for the people in the rural and peri-urban in order to reduce the rural -urban migration in search of better life and other opportunities.
- Education level of the head of household showed significant association with household food insecurity, thus more focus needs to be put in educating the population by making easy and low-cost enrolment in several educational institutions around the country. When the head of household is educated, it is easier for him/her to educate the rest of the family members and more likely to be familiar with modern technology that might be useful for his/her house wellbeing. Thus, strong policies are needed for strengthening both formal and informal adult education and vocational training to both rural and urban areas.
- There is a need for effective interventions to create awareness as well as for primary prevention strategies for cardiometabolic risks and its complications in Unguja Island, using local multidisciplinary approaches in the local language, Swahili. Additionally, there is a need for health surveillance initiatives for all age groups. These can also be used to help monitor prevention activities.
- Considering to the high proportion of the participants being overweight/obese, with population strategies for prevention of overweight and unfavourable lifestyle behaviours starting early in life in order to prevent it from happening to children in their adulthood, the long-term cardiovascular health and obesity-related inflammation of the entire population may be improved. In addition, there is a need to clarify how poor dietary intake and poor lifestyle habits promote adiposity and associated risk factors.
- There is need to create awareness about the risk factors of inflammatory disorders i.e. unhealthy diet and lack of physical activity. Education department, Ministry of Health and other related institutions can play important role by organizing events of healthy activities to make people aware and adoption of healthy life styles.
- Longitudinal studies with larger sample-sizes are recommended, to further investigate the relationship between food insecurity and the impact on nutrition and health of the people of Zanzibar Island as a whole.

- The currently used cut-off value (men: 94cm and women: 80 cm) for waist circumference may over predict abdominal fat excess in women in black Africa population, further research is needed to provide appropriate cut-offs for sub-Saharan African population. A large population-based study in Zanzibar could be a starting point.
- Very few research institutions in Tanzania focus on public health research and the related issues. Tanzanian governments need to develop initiatives that accelerate and support research and research-based education in the country, in order to build a solid foundation for research, increase research capacity and enable institutions to provide valuable training and develop sustainable research opportunities for young researchers.

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8 Annex: Publication 1-5

Publication 1

Original Paper

Design, Response Rates, and Population Characteristics of a Cross-Sectional Study in Zanzibar, Tanzania

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Abstract

Background: Data on nutritional status and correlates of noncommunicable diseases are scarce for resource-poor settings in sub-Saharan countries. With the scope of a project, "Access to Food and Nutrition Status of the Zanzibari Population," data for investigating public health questions were collected using proven measurement and laboratory standards.

Objective: The present study aims at providing a descriptive overview of recruitment approaches, standardization, quality control measures, and data collection, with special attention to the design, responses, and participant characteristics of the overall project.

Methods: A cross-sectional study across 80 randomly selected Shehias (wards) was conducted in 2013 in Unguja Island, Zanzibar. Examinations included all members living in 1 household, face-to-face interviews and anthropometric measurements (weight, height, mid-upper arm circumference, waist and hip circumference, and body composition) were assessed for all household members, blood pressure was taken from participants older than 2 years, and biosamples (urine and blood) from eligible household members were collected. Data collected from the core sample included sociodemographic data, nutritional status, and medical history (hypertension). Physical activity data was collected from a subsample of children between 3 and 16 years of age.

Results: A total of 1314 participants (mean age 23.6 ± 18.9 years, 54.54% female) completed all anthropometric measurements and were included in the analysis. Out of which, 98.40% (1293/1314) completed the household member's questionnaire, 93.32% (1229/1314) participants older than 2 years completed blood pressure measurements, and 64.31% (845/1314) blood samples were collected from participants older than 5 years. Underweight prevalence for the total study population was 36.53% (480/1314) with the highest prevalence in children under 14 years. Overweight and obesity was highest among females with the prevalence of 7.61% (100/1314) and 6.62% (87/1314), respectively; obesity was rare among male participants.

Conclusions: The study provides valuable data to investigate the interplay of socioeconomic, demographic, environmental, physiological, and behavioral factors in the development of diet-related disorders in a representative sample of the Zanzibari population.

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KEYWORDS

cross-sectional study; anthropometric measures; blood pressure; biosamples; response rates; sub-Saharan Africa

Introduction

Food and nutrition insecurity is defined as the uncertain or limited access to safe, sufficient, and adequate food that is supported by an environment of adequate sanitation and health services to allow a healthy and active life [1]; it is a leading cause of morbidity and mortality worldwide. The United Nations Food and Agriculture Organization (FAO) estimates that approximately, 1 in 9 people was suffering from chronic undernourishment in 2012-2014, with a high prevalence in sub-Saharan African countries with low income [2]. Although some of these countries report to have adequate food at the national level, this does not guarantee food security at the household level [3]. Access to food in Zanzibar is one of the foremost food security problems for many Zanzibar households in both rural and urban areas. Access to food means individuals have adequate income or other sources to purchase or obtain levels of appropriate foods needed to maintain consumption of an adequate diet/nutrition level and are able to obtain these foods in socially acceptable ways [4].

Food insecurity has been linked to poor diet quality and has been found to have multiple negative health impacts beyond under nutrition, such as hypertension, obesity, and increased rates of gestational diabetes mellitus [5,6]. Also, data from mainland Tanzania show an increasing prevalence of overweight and obesity in urban, peri-urban, and rural areas [7-9]. In Zanzibar, education, food production, globalization, and sedentary lifestyle have noticeable effects on the health and nutrition status of the people. Like other developing countries, Zanzibar is undergoing a double burden of underweight and overweight/obesity [10] with a rapidly increasing number of noncommunicable diseases and associated risk factors. Data on nutrition and lifestyle factors and related determinants to assess the prevalence of cardiometabolic risk factors are scarce for resource-poor settings in sub-Saharan countries.

The project “Access to Food and Nutrition Status of the Zanzibari Population” comprises a population-based, cross-sectional survey in order to collect data for addressing these public health questions using proven measurement and laboratory standards [11,12]. The present study aims to describe the study design, field methods, and examination modules that were used to collect data in this representative study population. The present study will also present response proportions for all survey modules, prevalence estimates for underweight, overweight, and obesity for all study participants, and measures for data quality as well as giving a first glance on estimates of metabolic and nutritional markers of malnutrition for the study population. Further results on nutrition and health outcomes related to food access and food insecurity, diet, and biochemical indicators, as well as the potential determinants of nutritional status of the study participants are the subject of forthcoming publications.

Methods

Study Area

Zanzibar Island is located approximately 25 km off the coast of Mainland Tanzania. Zanzibar is comprised of 2 main Islands, Unguja and Pemba, with a projected population of 1.3 million people; almost 63% living in Unguja and 37% in Pemba [13]. Zanzibar Island has 2650 km^2 of land area, of which two-thirds is coral-derived and one-third, where the population is concentrated, is good for agricultural production. Based on the food security situational analysis of 2006, Zanzibar produces 59% of its needs and the rest is from imports. The major foods produced are rice, cassava, bananas, sweet potatoes, maize, yams, and fish, while major imports includes rice, wheat flour, maize flour, and sugar [14].

Administratively, Zanzibar is divided into 5 regions, 3 in Unguja, and 2 in Pemba. Each region has 2 districts under the District Commissioner; each district is also subdivided into several smaller administrative units known as Shehias (equivalent to wards).

Sampling

This baseline survey was carried out in 80 Shehias in Unguja. A two-staged sampling technique was used: (1) from a list of all 213 Shehias from the Tanzania population and housing Census 2010 [15], 80 Shehias were randomly selected using a Statistical Software procedure PROC SURVEYSELCT; and (2) participating households were randomly selected within each Shehia through the official Sheha’s (the Shehia’s administrative authority) registration where all members of each Shehia were registered according to household number and/or street name.

Households were defined as a group that shared meals and slept under the same roof [16], all members in a household constituted the target study population. The overall aim of the study was to estimate the prevalence of malnutrition in the Zanzibari population including possible correlates. As published prevalence estimates for malnutrition in the overall population are scarce, malnutrition prevalence among children under the age of 5 years (30% prevalence of chronic malnutrition in children <5 years) was taken from the Tanzanian Demographic and Health Survey 2010 [13]. Assuming a prevalence of approximately 30% malnutrition in children <5 years of age, a sample size of 323 children <5 years of age was needed to estimate 95% confidence interval with a precision of ±5%. The estimated sample size was determined based on the formula discussed by Lemeshow [17]. Given that each household takes care of 1 child <5 years of age and the reported average household size is 4.8 members [15], we estimated a final sample size of 1453 subjects when 4 households per Shehia were enrolled.

Recruitment

Eligible households/participants were visited twice for recruitment and examination: during an evening visit, members of selected households were asked for agreement in participation, and on the subsequent morning they were examined. The field team randomly selected participating households by choosing any number from the household registration book. With the Sheha’s assistance, the selected households were visited for further information about the survey and enrollment, and to receive informed consent for all household members. Morning visits were for conducting all measurements, questionnaires, collection of morning spot urine and venous blood, distribution of accelerometers to eligible members, and providing feedback to all participants. Blood drawing and anthropometric measurements were carried out in fasting status.

All members of the selected households living together and eating from 1 pot were considered eligible. The main respondent was the head of household (father/mother). However, in the absence of the head of household, a guardian/caretaker of the house became the main respondent. In the case of polygamous families, all wives and their household members were also eligible for participation regardless of area of residence. One consent form was available per household; all participating members were given an anonymized identification number. Prior to the data collection process, all participants were verbally informed in Swahili on the study goals, purpose, target study group, contents, the amount of examinations involved, and that participation in the study was voluntary and consent could be withdrawn at any time without specifying any reason. Besides the verbal information given, all participants older than 16 years gave written consent and parents/guardians gave written consent on behalf of their children younger than 16 years. Participants signed 2 copies of the consent form, whereby 1 remained with them and the second was kept in the investigator's file on site. The study was approved by the Ethics Committees of the University of Bremen and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee in accordance with the ethical standards laid down in the Declaration of Helsinki and its later amendments. The consent forms were approved by the Institutional Ethics Committee.

As an incentive, every participating household received a Swahili feedback sheet with information on anthropometric measurements, body composition, blood pressure, and urine dip stick test results (for feedback purposes only).

Anthropometric Measurements and Physical Examinations

The survey covered standard anthropometric measurements taken by trained fieldworkers following standardized procedures for anthropometric measurements, physical examination [11,18], and biosample collection and procession [12].

The measurement of body composition and body weight was carried out using an electronic scale (TANITA BC-420 SMA, Germany) to the nearest 0.1 kg. The surveyed area was a strict Muslim community; participants were covered with light clothing ("Kanga"). Like many similar studies [19,20], the weighing scale was tared with 1-kg clothing to give a zero reading before weighing the participant. At each instance, the actual weight of the participant was measured in fasting status and barefooted.

Height of participants who could stand alone was measured in accordance with international standards for anthropometric assessment and weight (kg) [11]. Recumbent length of young children under 2 years was measured using a measuring board (Seca 417 measuring board, UK); all measurements taken were recorded to the nearest 0.1 cm. Body mass index (BMI) was calculated by dividing weight in kilograms by height squared in meters (kg/m^2) and then transformed to age- and sex-specific z-score. According to World Health Organization (WHO) [21] recommendations, BMI (adults) and BMI z-score (children) were used to define individuals who are underweight, normal weight, overweight, and obese.

Mid-upper arm circumference (MUAC) was measured at the mid-point of the left arm. Waist circumference (WC) was measured at the midway point between the lower rib margin and the iliac crest, and hip circumference (HC) was measured at the widest portion of the buttocks. Waist-to-hip ratio was obtained by dividing WC by HC. All circumferences were measured in standing position and while wearing light clothing using an inelastic measuring tape (SECA 201) to the nearest 0.1 cm.

A digital automatic blood pressure (BP) monitor (Omron T3) was used by trained fieldworkers to measure the systolic and diastolic BP according to a standardized procedure. Cuff length for BP measurement was determined according to the arm circumference, which was measured to the nearest 0.1 cm using an inelastic measuring tape. Participants were asked to rest for at least 15 minutes before measurements. Two measurements were taken at an interval of 5 minutes apart, plus a third measurement in case of a >5% difference in BP between the previous 2 readings. Use of antihypertensive medication and name(s) of medication were also recorded. For statistical analysis the lowest reading was considered. Hypertension was defined as a sustained high BP (systolic BP≥140 mm Hg or diastolic BP≥90 mm Hg) [22], or reported regular use of antihypertensive medication.

Questionnaires

All forms and questionnaires were administered and well explained by trained fieldworkers in Swahili. Three main questionnaires (ie, head of household questionnaire, household members' questionnaires, and young children questionnaire) were developed to collect data needed for the assessment. The questionnaires used were partly adapted from the Tanzania Demographic Survey 2010 [13] and Food and Nutrition Technical Assistance [23]. A partly validated head of household questionnaire was developed and administered to the head of the household (man/woman/guardian). This was used in collecting data on social, demographic, and economic indicators of the household: the ownership of livestock and other assets, sanitation, as well as information on household dietary behavior including expenditure and consumption. The household questionnaire also included a Swahili-translated version of Food Insecurity Experience questions [3], adapted from the original FAO 2007 [24]. Another tool used to measure food security was the Food Consumption Score, which was a composite score based on dietary diversity, food frequency, and relative nutritional importance of different food groups [25]. To measure nutritional quality and micronutrients adequacy of individual's diets, an Individual Dietary Diversity Score was calculated based on the 14 food groups' classification recommended by FAO (2007) [24]. Data derived with these instruments will be investigated in depth later and go beyond the scope of this study.

A (parental) proxy questionnaire was used to assess dietary diversity and consumption frequency of young children (0-24 months) addressing in particular breast-feeding habits, introduction to complimentary food, and a 24-hour dietary recall with food frequency questions adopted from the WHO [26].

Biosamples

The study collected venous blood and morning urine samples from eligible participants in an overnight fasting status, all participants were informed during the evening visits to avoid eating or drinking anything (apart from water) prior to sample collection. According to several identified studies and guidelines [27], pediatric blood sample volume limits ranging from 1% to 5% of total blood volume within 24 hours is within the limits of minimal risks. In this study, venous blood was drawn from participants older than 5 years and the collection was restricted to 1% of the estimated total blood volume corresponding to approximately 8 mL in a child weighing 10 kg. Children between 5 and 10 years received an eutectic mixture of local anesthetics patch prior to the blood drawing. For healthy, nonpregnant adults weighing at least 50 kg, a maximum of 20.5-mL venous blood was drawn, this corresponds with other research guidelines for human blood drawing. Instructions and urine collection cups labelled with the identification number of the participants were given to each member of the household for morning urine collection. Morning urine of younger children was collected by the parents.

A 6-mL tube (4 mL for children) of ethylenediamine tetraacetic acid (EDTA) blood was collected from each participant and kept at 4°C and fractioning was done the same day in the laboratory. First, 0.5-mL whole EDTA blood was transferred into a 2-mL cryotube for glycated hemoglobin (HbA1c) analysis. Second, the EDTA blood was further separated after centrifugation for 10 minutes at 2500 *g*: this includes partitioning of the sample in 2 aliquots of plasma (0.5-1 mL) and 2 aliquots of red blood cells (RBC), as well as the isolation of 0.5-mL buffy coat white blood cells (WBC). Plasma, WBC, and RBC aliquots were sorted into separate cryoboxes and immediately stored at −80°C. From each participant, a 25-mL sample of urine was collected. Of the collected urine, 4 aliquots (5 mL) were transferred to a 5-mL vial. The urine samples were sorted into a separate cryobox for later analysis and stored in an upright position at −80°C. Blood and urine samples were analyzed for indicators of metabolic disorders and other health- and diet-related outcomes like blood glucose, HbA1c, cholesterol, triglycerides, low-density lipoprotein (LDL), insulin, leptin, C-reactive protein, urine albumin, and cytokines like tumour necrosis factor-α, inducible protein-10, interleukin (IL)-6, IL-8, IL-15, and IL-1 receptor antagonist.

Physical Activity

To measure objective physical activity data, a subsample of 102 children and adolescents, aged between 3 and 16 years, were randomly selected from the participated households in 20 Shehias covering the rural, urban, and peri-urban areas. Participants wore a uniaxial accelerometer on the right side of the hip for 3-7 consecutive days. Raw data collected by the accelerometer were integrated into 15-second epochs using ActiLife software. Wear time and nonwear time were determined using the algorithms developed by Choi et al [28]. Nonwear time was defined as 90-consecutive minutes of 0 cpm, allowing up to a 2-minute interval of non-zero cpm. Information regarding the correct wearing of the accelerometer was explained to the parents and the participants prior to the initial wear. Both parents and participants were instructed to remove the accelerometer during sleeping, bathing, swimming, or at any point where they had full body contact with water. Parents checked and corrected the accelerometer on regular basis and used a diary to document the times and durations when the accelerometer was not worn or removed for specific reasons. These diaries were returned to the survey team mostly incomplete, and thus were not yet considered for analysis. Accelerometer measurements were included from children who wore the accelerometer for at least 3 days, including 1 weekend day, and for at least 6 hours per day. The duration of moderate-to-vigorous physical activity was determined according to the cut-offs of Evenson [29,30].

Quality Control and Management

All measurements and methods followed standard operation procedures and were adopted from the Identification and prevention of the Dietary- and lifestyle-induced health EFfects in Children and InfantS study (IDEFICS) [11,12]. All instruments were developed in English and translated to Swahili and then back-translated to check for translation errors. The quality of translation and the relevance of the study and instruments were discussed with the team of experts from the Ministry of Agriculture under the department of Food and Nutrition and the United Nations Children's Fund in Unguja.

Field workers participated in local training in Zanzibar prior to the pretest; the fieldworkers were trained from basic interview techniques to the specific anthropometric measurements data collection as well as field methodology and sampling. Further training on laboratory procedures (ie, collection, processing, and storage of biosamples) and analysis were provided to laboratory technicians according to the IDEFICS study standards [12].

Prior to field work, a pretest was conducted in a convenience sample to test the wording flow, comprehension of the questions, and interviewing and anthropometric measurements techniques; the instruments were then modified accordingly. All instruments were finalized after the pretest of all measurements.

Fieldworkers were divided into 2 teams who used the same technical equipment and instruments for data collection to maximize comparability of data. Reliability measurement results were assessed by repeated measurements and swapping of the field team members on a regular basis. Quality control was applied daily during the field phase and included completeness, quality of documentation, and adherence to the study procedures. All numerical variables were entered twice, independently during data entry. In order to decrease measurement errors, subsamples of the study subjects were examined repeatedly to calculate the inter- and intraobserver reliability of anthropometric measurements. The protocol of the reliability measurements proposed that the manual set of anthropometric measurements (excluding those that were measured with an electronic and automated device) be taken in at least 20 children (10 girls and 10 boys, all primary school). Every observer measured each child 3 consecutive times within 1 hour in an extra sample. Analysis was performed according to Stromfai et al [11].

Quality control during biosample analysis comprised double analysis in most parameters where feasible (HbA1c, glucose, total cholesterol, triglycerides, LDL), and a third scan when the difference between the first 2 values was >10%. Other parameters were measured once, and reference samples (n=6) were scanned randomly in an independent laboratory in

Germany controlling for interassay reproducibility of values. Interclass coefficient correlation between the 2 sets was calculated for the measurements of cholesterol, glucose NaF, HbA1c, HDL-cholesterol, LDL-cholesterol, LDL-HDL-quotient, and triglycerides.

Results

Household Characteristics

The household characteristic was comprised of the number of households that participated in the survey, household size, sex, marital status, highest head of household's education level, source of income, as well as occupation (Table 1). A total of 239 households participated in the survey, more than half (131/239, 54.8%) were from rural areas with an average household size of 6 persons per household. Of the participated households, 62.8% (150/239) were headed by a male. Over half (124/226, 54.9%) were married in monogamy with the highest percentage from rural areas (69/124, 55.7%). The results further showed that more than three-quarters (184/224, 82.1%) of the household heads had attained some level of education, which means they could read and write; 17.9% (40/224) had no education. Of the respondents, 49.0% (117/239) had no regular income, and 45.6% (109/239) had at least 1 source of income to ensure stability of household food supplies, with a majority (73/109, 55.7%) of the respondents being from a rural area, and 5.4% (13/239) with more than 1 source of income. Primary sector (farmer, livestock, fishing, daily ages) was the main occupation group for the majority (73/215, 30.7%) of the household heads.

Table 1. General characteristics of head of households.

Characteristics	Rural	Urban	Peri-urban	Total
	n (%)	n (%)	n (%)	n (%)
Number of households	131 (54.8)	53 (22.2)	55 (23.0)	239
Average number of household members	6.0	8.1	7.1	6.7
Gender of household head (n=239)				
Male	81 (61.8)	37 (69.8)	32 (58.2)	150 (62.8)
Female	50 (38.2)	16 (30.2)	23 (41.8)	89 (37.2)
Matrimonial status (n=226)				
Other[a]	20 (16.1)	13 (26.5)	10 (18.9)	43 (19.0)
Monogamous	69 (55.7)	27 (55.1)	28 (52.8)	124 (54.9)
Polygamous	35 (28.2)	9 (18.4)	15 (28.3)	59 (26.1)
Education of the household head (n=224)				
None	28 (22.8)	5 (10.4)	7 (13.2)	40 (17.9)
Primary	38 (30.9)	19 (39.6)	16 (30.2)	73 (32.6)
Secondary	56 (45.5)	23 (48.0)	29 (54.7)	108 (48.2)
Tertiary	1 (0.8)	1 (2.1)	1 (1.9)	3 (1.3)
Source of income (n=239)				
None	50 (38.2)	35 (66.4)	32 (58.2)	117 (49.0)
One	73 (55.7)	18 (34.0)	18 (32.8)	109 (45.6)
More than one	8 (6.1)	0 (0)	5 (9.1)	13 (5.4)
Occupation sector (n=215)				
None	40 (33.1)	27 (60.0)	26 (53.1)	93 (43.3)
Primary[b]	52 (43.0)	5 (11.1)	9 (18.4)	66 (30.7)
Secondary[c]	3 (2.5)	1 (2.2)	3 (6.1)	7 (3.3)
Tertiary[d]	26 (21.5)	12 (26.7)	11 (22.5)	49 (22.8)

[a]Other includes single, divorced, widow, and cohabitation.

[b]Primary sector includes agriculture, fishing, mining, and forestry.

[c]Secondary sector includes craftsman and industry and construction work.

[d]Tertiary sector includes services and trade.

Age and Gender Distribution of the Study Population

Table 2 represents age distribution of the study population by gender. The sample consisted of 1314 participants; age ranging from 0 to 95 years with a mean (SD) of 23.6 (SD 18.9) years. Participants were predominantly women (715/1314, 54.41%), of which 54.0% (386/715) were between 15 and 59 years. Working and reproductive age adults (15-59 years) comprised 50.15% (659/1314) of the total study participants, 15.60% (205/1314) of the population were children younger than 5 years, 28.01% (368/1314) were school-age children between 6 ad 14 years, and 6.62% (87/1314) were elderly participants.

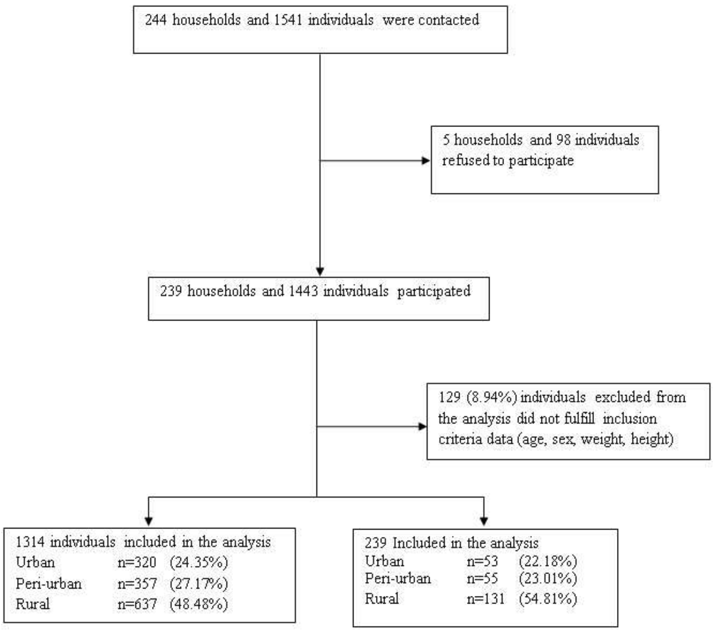
Table 2. Age distribution of the study population stratified by gender.

Age group in years	Male	Female	Total
	n=599 (45.59%)	n=715 (54.41%)	N=1314 (100.00%)
0-2	27 (4.51)	36 (5.03)	63 (4.79)
3-5	67 (11.19)	75 (10.49)	142 (10.81)
6-14	192 (32.05)	171 (23.92)	363 (27.62)
15-59	273 (45.58)	386 (53.99)	659 (50.15)
60+	40 (6.68)	47 (6.57)	87 (6.62)

Participation and Responses

Out of 323 targeted households, 244 households were contacted, of which 97.9% (239/244) were included in the analysis and 2.1% (5/239) of households refused to participate. There were 1453 individuals targeted; however, due to high number of household members 1541 subjects were contacted, of which 1443 took part in 1 or more examination and questionnaire. Overall, 1314 participants fulfilled all inclusion criteria (weight, height/length, age, and gender) and were included in the analysis (Figure 1).

Figure 1. Flow diagram of participants from recruitment to analysis.



Biomarkers in Urine and Blood

Table 3 presents proportions of analyzed biomarkers in urine and venous blood (≥5 years) stratified by age group. Approximately 63.5% (389/613) of the biosamples collected were from 15- to 59-year olds and the lowest proportion (8/585, 1.4%) was from children younger than 5 years, followed by elderly participants older than 60 years (58/613, 9.5%).

Table 3. Bio markers in urine and venous blood samples.

Biosample	Biomarker	<5 years n (%)	6-14 years n (%)	15-59 years n (%)	>60 years n (%)	Total n
Urine						
	Urine albumin-to-creatinine ratio[a]	85 (12.2)	202 (29.1)	353 (50.8)	55 (8.0)	695
Blood						
	Cholesterol[b]	6 (1.1)	152 (26.0)	372 (63.6)	55 (9.4)	585
	Glucose[b]	6 (1.0)	15.2 (26.0)	373 (63.7)	55 (9.4)	586
	Low-density lipoprotein[b]	7 (1.2)	15.2 (26.0)	372 (63.5)	55 (9.4)	586
	Triglycerides[b]	7 (1.2)	152 (26.0)	373 (63.5)	55 (9.4)	587
	C-reactive protein[c]	7 (1.2)	152 (26.0)	373 (63.5)	55 (9.4)	587
	Insulin[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	Leptin[c]	8 (1.3)	159 (25.9)	389 (63.5)	57 (9.3)	613
	IL[d]-1Ra[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	IL-6[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	IL-8[c]	8 (1.3)	159 (25.9)	389 (63.5)	57 (9.3)	613
	IL-15[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	Inducible protein-10[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	Tumor necrosis factor-α[c]	8 (1.3)	158 (25.8)	389 (63.5)	58 (9.5)	613
	HbA1c[e,f]	7 (0.9	219 (26.9)	524 (64.3)	65 (8.0)	815
	Homeostatic model assessment-insulin resistance[g]	6 (1.0)	151 (26.1)	369 (63.6)	54 (9.3)	580

[a]Data available for some of the urine samples collected (at date of publication of manuscript).

[b]Measured in NaF plasma.

[c]Measured in blood serum.

[d]IL: interleukin.

[e]HbA1c: glycated haemoglobin.

[f]Measured in ethylenediamine tetraacetic acid blood (n=870).

[g]Homeostatic model assessment index = insulin (fasting, µU/mL) × blood glucose (fasting, mmol/L)/22.5.

Individual Response for All Survey Modules

Core survey modules listed in Table 4 included questionnaires, anthropometric measurements, venous blood, BP, and a subsample for accelerometer use with children between 3 and 16 years. Besides the anthropometric measurement that had the minimum requirement inclusion for analysis (age, sex, height, weight), 100% response was not reached for other modules. The overall response rate for completing questionnaires was 98.40% (1293/1314); 64.31% (845/1314) for venous blood (restricted to participants ≥5 years), and 93.53% (1229/1314) for BP (participants ≥2 years). The use of an accelerometer was planned in a small subsample group of children between 3 and 16 years and was assessed in 95 children.

Table 4. Response of participants for all survey modules by age group.

Measurements/ examinations	Age group in years					Total	Overall response rate
	0-2	3-5	6-14	15-59	≥60		
	n (%)	n (%)	n (%)	n (%)	n (%)	n	%
Anthropometric measurements	63 (4.79)	142 (10.78)	364 (27.70)	659 (50.15)	86 (6.54)	1314	100
Household members questionnaire	60 (4.64)	142 (10.98)	358 (27.69)	648 (50.12)	85 (6.57)	1293	98.40
Venous blood[a]	-	8 (0.95)	233 (27.57)	537 (63.55)	67 (7.93)	845	64.31
Blood pressure[b]	-	124 (10.09)	364 (29.62)	655 (53.30)	86 (7.00)	1229	93.53
Accelerometer[c]	-	10 (10.53)	79 (83.16)	6 (6.32)	-	95	7.23

[a]Not measured in children below 5 years.

[b]Not measured in young children below 2 years.

[c]Measured only in a subsample of children and adolescents between 3 and 16 years (n=95).

Prevalence of Malnutrition

Table 5 represents the prevalence of nutritional status according to gender and age group of the entire study population. The overall prevalence of underweight, overweight, and obesity was 36.45% (479/1314), 13.09% (172/1314), and 8.14% (107/1314), respectively; 42.31% (556/1314) of participants had normal weight. A higher proportion 70.24% (144/205) of children below the age of 5 years were underweight, more boys were underweight compared with girls. Adult females ages 15-59 years were more obese (71/386, 18.39%) compared with males of the same age group. One-third (28/87, 32.18%) of the elderly participants, both male and female and 60+ years, were overweight, and 16.09% (14/87) were obese.

Table 5. Prevalence of nutritional status stratified by gender and age group.

Gender/age group	Underweight	Normal weight	Overweight	Obese	Total
	n (%)	n (%)	n (%)	n (%)	n
Male					
0-5 years	69 (73.40)	22 (23.40)	2 (2.12)	1 (1.06)	94
6-14 years	120 (62.18)	69 (35.75)	1 (0.52)	3 (1.55)	193
15-59 years	56 (20.51)	149 (54.58)	56 (20.5)	12 (4.40)	273
60+ years	7 (17.95)	14 (35.90)	13 (33.33)	5 (12.82)	39
Total male	252 (42.07)	254 (42.40)	72 (12.02)	21 (3.51)	599
Female					
0-5 years	75 (67.57)	27 (24.32)	4 (3.60)	5 (4.50)	111
6-14 years	93 (54.39)	63 (36.84)	13 (7.60)	2 (1.17)	171
15-59 years	53 (13.73)	194 (50.26)	68 (17.62)	71 (18.39)	386
60+ years	6 (12.77)	17 (36.17)	15 (31.91)	9 (19.15)	47
Total female	227 (31.75)	301 (42.10)	100 (13.16)	87 (12.17)	715
Total					
0-5 years	144 (70.24)	49 (23.90)	6 (2.93)	6 (2.93)	205
6-14 years	213 (58.68)	132 (36.36)	14 (3.86)	4 (1.10)	363
15-59 years	109 (16.54)	343 (52.15)	124 (18.82)	83 (12.59)	659
60+ years	13 (14.94)	32 (36.78)	28 (32.18)	14 (16.10)	87
Overall	479 (36.45)	556 (42.31)	172 (13.10)	107 (8.14)	1314

Quality Indicators

Results of inter- and intraobserver technical error of measurements (TEM) were generally low. Interobserver reliability as assessed by the R for repeated measurements of height, MUAC, WC, and HC was above 99% for all participants (Table 6). TEM% provides comparability of quality between measurements.

Table 6. Inter- and intraobserver technical error of height and circumferences of the arm, waist, and hip in an extra sample.

	Interobserver				Intraobserver (n=30)			
	Mean	TEM[a]	TEM%	R%	Mean	TEM	TEM%	R%
Height	1.36507	0.003524036	0.25816	99.98	1.27973	0.003570410	0.27900	99.99
MUAC[b]	0.21628	0.001305582	0.60365	99.95	0.20203	0.004684696	2.31877	99.35
WC[c]	0.66582	0.001857418	0.27897	99.98	0.59423	0.007834197	1.31837	99.73
HC[d]	0.76888	0.007254823	0.94356	99.86	0.70237	0.004697209	0.66877	99.94

[a]TEM: technical error of measurements.

[b]MUAC: mid upper arm circumference.

[c]WC: waist circumference.

[d]HC: hip circumference

Discussion

Participation and Response

Currently, there are no existing studies that collected anthropometric, biological, socioeconomic, and nutritional data in a representative study sample in randomly selected households in Zanzibar following standardized procedures. This study was successful in setting up a cross-sectional survey of over 1400 participants in 80 Shehias across Unguja. The study included young children to elderly participants ages 0-95 years. The response rate was higher than expected. This is most probably due to multiple reasons: (1) a good training of the field workers in giving out information to participants, (2) feedback on results that are normally not affordable if requested by a physician, and (3) support through the Shehas who clearly had an interest in the results of the study. Prior to the start of the survey, all Shehas were invited to a presentation of the aims and content of the study (examinations) and to request official approval and support by the Shehas. Information on this meeting was disseminated in the local media, describing the aims of the study, which led to an overall high acceptance among participating families. Further, all the measurements and examinations were conducted at the participant's homes and at their convenient time, having the advantage that all eligible individuals could be enrolled regardless of child care or (home) work. Our finding of an average household size of 6.7 compared with the officially reported average household size of 4.8 [15] supports that an official dissemination of study aims and measurements is a useful strategy to enhance response proportions for complete households. Also, the feedback sheets on personal measurements were appreciated and were useful to enhance response rates at family and community level. A feedback on all parameters of interest was promised to all Shehas, researchers, politicians, and stakeholders of health services prior to the survey and was presented 1 year after survey termination at a 2-day workshop in Zanzibar. Also, this workshop and the results were disseminated through the local media (television, newspaper) in order to give feedback to the general population.

However, approximately 11.29% (129/1443) of participants were excluded from the study for not fulfilling all criteria (weight, height/length, age, and sex) needed for analysis. This was due to respondents not knowing their exact date of birth and/or not having any records. Comparable to our results, Korkalo et al [31] encountered a similar problem in their study. Reasons for refusing anthropometric measurements were: pregnancy, illness/weakness, or fear in young children <2 years; a similar challenge was discussed in a previous study [32].

Quality Control

Anthropometric measurement error is unavoidable and should be minimized by high-quality standards regarding every aspect of the data collection process. In all cases intra- and interobserver reliability for all measurements was greater than 99%, these results are very similar and even better than other reported studies [11,33,34]. Comparison of results from this study to previous investigated TEM and R values indicated that height and MUAC were similar and within the range with the reference values recommended for intraobserver values by Ulijaszek and Kerr [33]. Interobserver reliability for all circumferences was above 99%, other researchers reported ranges for MUAC 94%-100% , WC 86%-99%, and HC 68%-99% [33]. Compared with above results, the present data prove a high degree of accuracy during examination. We conclude that the local training and using the rigorous standardization approach facilitated the collection of accurate and comparable data.

For quality control of the biosamples, data collection, processing, and storage, protocol was adapted from IDEFICS study [32] that applied a quality management system for the collection of biological sample in epidemiology study; the system was developed and introduced by Peplies et al [12]. The results of the validation study and the very high level of agreement we observed underlines the need for standardizing biosample collection, procession, storage, and analysis, as well as for controlling the reliability of values obtained in order to repeat analysis if needed.

Anthropometry and Nutritional Status

This study provides information on the anthropometry and nutritional status of all members of household included in the survey. The comparison across Shehia, age groups, and gender facilitate focused nutrition interventions in these aspects. Although the mean BMI for both male and female was within the normal range (18.5-24.9 kg/m^2), both problems of underweight and overweight/obese were prevalent for both male and female. Among all study participants, 36.37% (479/1314) were considered to be underweight with a slightly higher prevalence in males (252/1314, 19.13%) compared with their female counterpart (227/1314, 17.28%). Of the 479 underweight participants, the highest proportion (213/479, 44.5%) was among school age children between 6 and 14 years. This result is almost similar to a study conducted in Nigeria (43.5%) for children between 9 and 12 years [35], and higher than studies conducted in India (38.4%) for children between 5 and 15 years [36], Mauritius (37.0%) for children between 8 and 12 years [37], and Uganda (13.0%) for children between 9 and 15 years [38]. The prevalence of underweight among young children <5 years was 70.1% (144/204), which is higher than reported in other studies conducted in sub-Saharan Africa for children <5 years in Tanzania Mainland (16%), Zanzibar (19%), Kenya (11.8%), and Cameroon (12.9%), respectively [13,39-41]. Although there are differences in sampling and target age groups, but nevertheless, the prevalence of underweight in our population-based survey among children <5 years and school age children 6-14 years is clearly higher than the above mentioned studies.

Overall prevalence of overweight and obesity is 13.1% and 8.1%, respectively, with the highest proportion in adult female participants ≥15-years old compared with their male counterparts. Prevalence of overweight and obesity for females 15- to 59-years old is 17.6% and 18.4%, respectively, and for elderly people above 60 years is 31.9% and 19.1%, respectively. This is found to be higher than that of the male participants, but lower than several studies conducted in Africa [42-45]. A higher prevalence of overweight and obesity among women has also been reported in other studies [13,44,45].

Strengths and Limitations

Age and gender are the primary basis for demographic classification and also very important variables in the study of mortality, fertility, and marriage [13]. As reported in the comprehensive food security and vulnerability analysis [46], Tanzania overall has a very young population due to its fertility rate in the past. The present study shows a similar trend for Unguja Island with approximately 43% of the population being <15 years, of which approximately 15% are <5 years of age. Unfortunately, the response rate for children <5 years is less than the expected sample size; this is due to the higher household size and that the priority of enrollment was given to entire families rather than on age. Nevertheless, we are confident that the overall sample size of 1314 individuals will enable us to investigate the aimed research question with sufficient statistical power.

A strong cooperation and support by the Shehas of the study Shehias facilitated an easy and problem-free collection of data. Standardized approaches and clear documentation of the field information made it easy and required less time for data editing and entry. This was possible due to a successful training of the survey team prior the field trips. Feedback results of the anthropometric measurements, urine test results, and BP were well appreciated incentives, which not only motivated the participants to take part, but also provided them with information on their health status immediately after the measurements and free of charge. One of the methodological challenges was taking anthropometric measurements from women and young children. Women wore several layers of light clothing during measurements, might have affected the measurements taken, and children were mostly playful and unstable during measurements. However, these challenges are unlikely to change the findings and prevalence because 1 kg for clothing was deducted from weight measurements for all participants. Another challenge encountered was that most of the participants did not know or could not remember their precise date, month, and/or year of birth; however, this problem was solved with the help of an event calendar developed by the field team prior to the field work. Despite these limitations in the method and data collection, recruitment and participation was very successful and data collected was a good representative of the population studied.

Conclusions

We can conclude that a rigorous standardization process and comprehensive training facilitated the collection of accurate and comparable anthropometric and biodata. The study provides valuable data to investigate the interplay of socioeconomic, demographic, environmental, physiological, and behavioral factors in the development of diet-related disorders in a representative sample of the Zanzibari population.

Further, investing time and endeavouring into a dissemination strategy involving important gatekeepers is a useful strategy to enhance response rates and acceptance in the study population. Transparency of population-based survey results at the individual, community, and governmental level are recommended at any time.

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We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. Approval by the Ethics Committees of the University of Bremen in Germany with a reference number 06-3 and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee in Zanzibar, Tanzania with a reference number ZAMREC/0001/AUGUST/013. Study participants did not undergo any procedures unless both children and their parents had given written informed consent for examinations, collection of samples, subsequent analysis, and storage of personal data and collected samples. Study subjects could consent to single components of the study while abstaining from others.

Authors' Contributions

This manuscript represents original work that has not been published previously and is currently not considered by another journal. The authors' responsibilities were as follows: AH and MAN had the idea of the analysis; MAN did the analysis, data interpretation, and wrote the manuscript, and had primary responsibility for final content and submitting the manuscript for publication; MAN, SK, MS, and AH were responsible for critical revisions and final approval of the manuscript.

Conflicts of Interest

None declared.

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Abbreviations

BMI: body mass index
BP: blood pressure
EDTA: ethylenediamine tetraacetic acid
FAO: Food and Agriculture Organization
HbA1c: glycated hemoglobin
HC: hip circumference
IDEFICS: Identification and prevention of the Dietary- and lifestyle-induced health EFfects in Children and InfantS study
IL: interleukin
LDL: low-density lipoprotein
MUAC: mid upper arm circumference
RBC: red blood cells
TEM: technical error of measurements
WBC: white blood cells
WC: waist circumference
WHO: World Health Organization

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Exploring Food Access and Sociodemographic Correlates of Food Consumption and Food Insecurity in Zanzibari Households

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Abstract: Rapid growth of the Zanzibari population and urbanization are expected to impact food insecurity and malnutrition in Zanzibar. This study explored the relationship between food access (FA) and sociodemographic correlates with food consumption score and food insecurity experience scale. Based on cross-sectional data of 196 randomly selected households, we first investigated the association between sociodemographic correlates and Food Consumption Score (FCS) and Food Insecurity Experience Scale using multilevel Poisson regression. Secondly, the role of FA in these associations was investigated by interaction with the respective correlates. About 65% of households had poor food consumption, and 32% were severely food-insecure. Poor FA was more prevalent in households with poor food consumption (71%). Polygamous households and larger households had a higher chance for severe food insecurity. In the interaction with FA, only larger households with poor FA showed a higher chance for severe food insecurity. In households having no vehicle, good FA increased the chance of having acceptable FCS compared to poor FA. By contrast, urban households with good FA had a twofold chance of acceptable FCS compared to rural household with poor FA. Poor FA, poor food consumption and food insecurity are challenging; hence, facilitating households' FA may improve the population's nutrition situation.

Keywords: demographic correlates; food access; household; food insecurity experience scale; Zanzibar; sub-Saharan Africa

1. Introduction

The world population is expected to increase by 2.5 billion between 2007 and 2050, with most of the growth foreseen to occur in urban areas of developing countries [1]. This rapid growth and urbanization are expected to increase poverty and negatively impact the food security environment of urban dwellers, leading to food insecurity and malnutrition [2]. According to the World Bank report from 2015 [3], 29% of Tanzanians could not meet their basic consumption needs, and about 10% of the population could not afford to buy basic food stuff. In Tanzania and other developing countries, the leading factor in household food insecurity in urban areas is the dependency on food purchase [2,4,5]. Therefore, a slight increase in food prices has a major impact on vulnerable households, pushing them into hunger and poverty [6]. About 80% of the household food requirement in peri-urban areas of

Unguja Island, Zanzibar is purchased [7,8], while about 60% of food consumed in rural areas is obtained through home gardening and farming [9]. Home gardening and farming contribute substantially to households' own food production [10] and may thus enhance household food availability and food security in rural areas. Own food production increases purchasing power, due to savings on food bills [4,11] and income from selling of the produce. It also provides a diversity of nutritious food that helps to improve the health status of the household [11] as well as serves as a means of food provision during food shortage.

Studies conducted in Nigeria [12] and Ethiopia [13] have shown that male heads of household (HH) play a substantial role in determining household food security, while others reported that female HH are more likely to spend most of their income on food, thus guaranteeing food security for their households [14,15]. Household size has also been shown to influence food security and acceptable food consumption, with smaller household size being associated with household food security [16] and acceptable food consumption, and large household size with poor food consumption and perceived food insecurity [17]. Food insecurity has also been found to be associated with low monthly income [18]. Income earned from any source improves the food situation of a household [19]; thus, households with more employed adult members are likely to have a better food situation compared to households with more unemployed adult members [20].

Several studies conducted in low-income countries, especially in Africa [4,5,16,18], have investigated the determinants of either household food security or food consumption behavior in households. However, this is the first study in Zanzibar that recruited randomly selected households and enrolled all members of a household for further insights on correlates of food insecurity and food consumption. The present study aimed to explore the relationship between food access (FA) and sociodemographic household factors with the Food Consumption Score (FCS) and Food Insecurity Experience Scale (FIES). Findings from this study can provide baseline information on the interaction between food access and household factors, and the collected data can be used for further research on health interventions to improve food consumption and food security in Zanzibar.

2. Materials and Methods

2.1. Study Area, Population, and Sampling

A population-based cross-sectional study was conducted in 2013 in Unguja Island, Zanzibar, whereby entire households were enrolled as sampling units. For the purposes of this study, a household is defined according to Beaman and Dillon [21], with emphasis on eating from the same pot, i.e., having the same food provider. This is particularly important as our study population consisted not only of monogamous but also of polygamous families, who do not necessarily live together in the same house or compound.

Household aspects were reported by the head of household in a questionnaire-administered personal interview. In total, 244 randomly selected households were contacted from 80 Shehias (wards), and 239 (97.9%) participated in the survey. Due to missing information on socioeconomic status, demographic correlates, and responses from FCS and FIES instruments, 43 households were excluded from the analysis, resulting in a final sample of 196 (82%) households. Further details on sampling procedures, data collection, and quality management are provided elsewhere [22].

Prior to the data collection process, all participants gave written, informed consent. All procedures applied in this study were approved by the Ethics Committees of the University of Bremen (in September 26, 2013) as well as the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee (ZAMREC/0001/AUGUST/013) in accordance with the ethical standards according to the 1964 Declaration of Helsinki and its later amendments.

2.2. Questionnaires

A structured household questionnaire was used to collect general household information. The information included data on socioeconomic and demographic indicators of the household and of the head of household, such as area of residence, number of animals owned, number of vehicles belonging to the household, household size, marital status, education level of the HH, occupation of the HH, etc. In cases of polygamy, household information was also collected from the households of the other wife or wives. Information on indicators of household food consumption was collected using a standardized questionnaire (Food Consumption Score, FCS), adapted from the United Nations World Food Programme (UNWFP) [23]. Household food insecurity was measured at the household level using a standardized questionnaire for the Food Insecurity Experience Scale (FIES), which was adapted from the Food and Agriculture Organization (FAO) [24]. All questionnaires were developed in English, translated into Swahili and back-translated to check for translation errors.

2.2.1. Food Consumption Score (FCS)

FCS is a composite score constructed from (1) household dietary diversity based on nine food groups (staples, pulses, fruits, vegetables, meat and fish, dairies, sugar, oil and fat, condiments) consumed during the 7 days preceding the survey, (2) food frequency, counted as the number of days each food group was consumed during the 7 days preceding the survey, and (3) relative nutritional importance of different food groups, applying a weighting system [23], thus reflecting the quality and quantity of food consumed in the household.

Higher weights were given to energy-dense foods with proteins of high quality and a range of bioavailable micronutrients, while lower weights were given to oil and sugar, which are energy-dense but contain—if any—proteins of low quality and low levels of micronutrients [25]. Cut-off points established by the UNWFP [23] were used to classify FCS. They were computed by summing up the weighted frequencies of the different food groups consumed in the household. FCS $\leq$ 28 was categorized as "poor", FCS > 28 and < 42 as "borderline", and FCS $\geq$ 42 as "acceptable" [23]. For the regression analysis in this study, poor consumption and borderline were merged to a new category, "poor", resulting in two categories of food consumption score, i.e., "poor" and "acceptable".

2.2.2. Food Insecurity Experience Scale (FIES)

Food insecurity was assessed using the Food Insecurity Experience Scale (FIES), a standardized set of questions developed by the FAO [24] that has been applied in a large number of countries following a standardized procedure. The scale, which is an experience-based metric of severity of food insecurity that relies on people's direct/actual responses, includes components of uncertainty and worry about food, inadequate food quality, and insufficient food quantity. It consists of a set of eight items that assess food-related behaviors associated with difficulties in accessing food due to limited resources. The instrument measures the degree of food insecurity/hunger experienced by individuals during the 12 months preceding the survey.

Household scores of food insecurity on the eight items were scaled based on a Rasch model as an application of the item–response theory (IRT) [26]. In IRT, the response to each item is modelled as a function of item and household parameters to measure the position of households on a latent trait, independently of the item difficulty. We conducted the Rasch model using the eRm package 0.16–2 [27] in R 3.5.1 to derive household scores for the following regression analyses. Households who responded 'no' to any of the eight items received the lowest value. Item characteristic curves indicated item reliability, and the person separation index was found to be high (0.84). Household scores ranged from −3.57 to 3.76 and clustered either to the lowest negative scores (<−2), around 0 (−2 to 2) or to the highest scores. Based on these cut-off points, we categorized household scores into mild, moderate, and severe (hunger), which are the three categories used by the FAO [24] to define levels of food insecurity/hunger. For the Poisson regression analysis, food security, mild and moderate food insecurity were dichotomized into "mild to moderate" (0) and "severe food insecurity" (1). A household is considered as food-secure if members have always had enough food and no hunger worries [24].

2.3. Correlates

Correlates of FCS and FIES were assessed for the HH (gender, education level, number of jobs, marital status) and at household level (household size, number of types of animals kept in the household, vehicles owned by any of the household members, area of residence, and food access). The highest education level of the HH was assessed using the International Standard Classification of Education (ISCED) [28] and was categorized for the analysis as low education level (primary school and below) and high education level (secondary school and above). Number of jobs of HH for assessing main household income was defined as "no job" and "≥1 job". Marital status of HH was calculated in three categories: Married monogamous, married polygamous, and other (single, widowed, cohabitating or divorced). To facilitate interpretation, two categories for marital status were derived: Married (monogamous or polygamous) and not married (single, widow, cohabitation, divorced). Cohabitation was categorized as "not married" since it is characterized by a different socioeconomic status compared to those households with married HH. Using the mean household size of 6 members in this study population as a cut-off, household size was classified as large (six or more members) and small (less than six members). To assess household wealth, the number of types of animals kept in the household from a list of six items including ducks, goats, sheep, cows, fish, and chicken, and the number of assets from a list of eight items including electricity, radio, mobile phone, iron, kerosene lamps, television, refrigerator, and non-mobile phone was summed up. The median number of animals and assets was five, and this figure was used to categorize wealth into wealthy (≥5) and poor (<5). The number of vehicles per household was assessed as type of transportation owned by any member of the household from a list of 5 categories (bicycle, car/truck, boat, motorcycle, none). Two categories were built: "none" and "at least one type of vehicle". Area of residence was assessed as rural or urban.

An important component of food consumption and food insecurity included in the analysis was FA. In this study, FA was defined as the ability of a household to acquire adequate amount of food through mixed strategies. Indicators for FA were assessed, and derived variables were combined to a composite score (see Table 1 below). The derived variables were: (a) Food source; main source of food consumed during the last seven days (purchased, borrowed, own production, traded food/barter, received as gift, food aid, other), (b) food purchased; types of food (cereals, starchy vegetables/ tubers, vegetables, fruits, legumes, meat, egg, milk, fish, oils and fats, any kind of beverage, other), frequently bought from shop/market during the last seven days, (c) own food; types of foods (from those listed above) of own household production, and (d) market distance; distance to the nearest market or shop (<30 min, 30 to 60 min, 1 h to 2 h, >2 h).

To classify households as having poor or good FA, a composite score for FA was computed as the mean of the values of the derived variables multiplied by 4 (number of all derived variables). The FA-score ranged from 4–8, and FA was then categorized as "poor food access" (≤6) and "good food access" (>6). The cut-off was set according to the distribution of FA-status in the study population, as half of the population included in the study had FA score of 6 and below.

Table 1. Overview of measured indicators for FA and derivation of variables for the composite score.

Indicator of Food Access	Derived Variable	Categories
Main source of food consumed One main source to be selected from 6 categories: purchased, borrowed, traded food/barter, received as gift, food aid, own production	Food source = one main source per household	1: borrowed, received as gift, food aid, other 2: own production, traded food/barter, purchased
Types of food groups frequently bought from shop/market Food group (e.g., cereals) out of 11 food groups was 0: not bought, 1: bought	Food purchased = sum of all food groups purchased	1: ≤4 food groups, 2: >4 food groups
Types of food groups of own household production Food groups out of 11 food groups 0: not produced (purchased, borrowed, traded food/barter, received as gift, food aid), 1: own production	Own food = sum of all food groups with own production	1: ≤2 food groups, 2: >2 food groups
Distance to the nearest market/shop far (>30 min walking distance); near (<30 min walking distance)	Market distance	1: far, 2: near

2.4. Statistical Analysis

Study characteristics such as socioeconomic and demographic variables were calculated for categories of food consumption and food insecurity. First, the associations between the exposure variables (food access, socioeconomic and demographic correlates) with either food consumption (FCS; Model 1) or food insecurity (FIES; Model 2) as outcome variables were explored. To explore these associations, linear, Poisson, and logistic regression models were considered and evaluated with regard to model fit and Pearson residuals as well as quantile-quantile (Q–Q) plots. Eventually, we conducted multilevel logistic regression models to calculate odds ratios (OR) and 95% confidence limits (CI) and to account for clustering within Shehia level using a random intercept. Secondly, statistical interactions between each correlate and food access (correlate*FA) were investigated. Hence, in Models 3a–h and 4a–h, the predictive power of each socioeconomic and demographic factor with FA on FCS and FIES was tested separately. Each model was again adjusted for the remaining correlates, including a random intercept for the Shehia level. All statistical analyses were performed using SAS 9.3 (SAS Institute, Cary, NC, USA). Due to the exploratory design of our study, we only considered confidence limits as a precision measure of the point estimates but did not apply a level of significance. Moreover, we did not adjust for multiple testing. Noteworthy associations are presented considering higher (OR > 1.5) or lower (OR < 0.66) chances for the modelled response category.

3. Results

3.1. Household Characteristics

The sample data were based on the responses of the HH. The majority of the households were headed by men (63%, 123/196), and about 55% of the HH (107/196) were in a monogamous marriage. More than half of the HH had one or more sources of income that he/she contributed to the household. Most of the households were in rural areas, and the overall mean household size of the participating households was 6 persons. More than 60% of the households had a good socioeconomic status, with one or more than one animal kept and at least one vehicle owned by a member belonging to the household. Overall, about 65% of the households had poor food consumption, and about 32% were severely food-insecure (Table 2). Acceptable food consumption was more prevalent in households with higher-educated HH (40%), in monogamous households (38%), and in larger households (six or more members) (38%). Severe food insecurity was more prevalent in polygamous households (40%), in households with low-educated HH (40%) and in larger households (six or more members) (40%). Looking at each question of the FIES, the majority of the households (73.5%) indicated having eaten few kinds of food in the last 12 months due to lack of money, and 26% went without eating for a whole day due to lack of money (Table 3). About 54% (106/196) of the study population had poor FA, of which 71% had poor food consumption and 35% experienced severe food insecurity.

Table 2. Proportion of food consumption and food insecurity experience scale according to demographic and socioeconomic factors.

	Food Consumption Score				Food Insecurity Experience Scale				Total
	Poor		Acceptable		Mild to Moderate		Severe		
	N	%	*N*	%	*N*	%	*N*	%	*N*
All	128	65.3	68	34.7	134	68.4	62	31.6	196
Household Demographics									
Gender									
Male	72	58.5	51	41.5	80	65.0	43	35.0	123
Female	56	76.7	17	23.3	54	74.0	19	26.0	73
Marital status of HH									
Not married [a]	27	79.4	7	20.6	28	82.4	6	17.6	34
Married monogamous	66	61.7	41	38.3	73	68.2	34	31.8	107
Married polygamous	35	63.6	20	36.4	33	60.0	22	40.0	55
Education level									
Low	69	71.1	28	28.9	59	60.8	38	39.2	97
High	59	59.6	40	40.4	75	75.8	24	24.2	99
Number of jobs									
No job	61	70.1	26	29.9	57	65.5	30	34.5	87
One or more jobs	67	61.5	42	38.5	75	68.8	24	22.2	109
Area									
Rural	105	68.6	48	31.4	102	66.7	51	33.3	153
Urban	23	53.5	20	46.5	32	74.4	11	25.6	43
Household size [b]									
Small	68	68.7	31	31.3	75	75.8	24	24.2	99
Large	60	61.9	37	38.1	59	60.8	38	39.2	97
Socioeconomic Factors									
Wealth (household assets and animals) [c]									
Poor	61	73.5	22	26.5	51	61.4	32	38.6	83
Wealthy	67	59.3	46	40.7	83	73.5	30	26.5	113
Number of vehicles									
None	31	72.1	12	27.9	28	65.1	15	34.9	43
At least one vehicle	97	63.4	56	36.6	106	69.3	47	30.7	153
Food access [d]									
Poor	75	70.8	31	29.2	69	65.1	37	34.9	106
Good	53	58.9	37	41.1	65	72.2	25	27.8	90

[a] Not married includes single, divorced, widow, and cohabitation; [b] cut-off was derived from the mean number of household members in this study, small (≤6) and large (>6); [c] wealth (poor <5 and wealthy ≥5, calculated as the median number of animals and assets in the household); [d] cut-off (poor ≤6, good >6).

Table 3. Questions of the Food Insecurity Experience Scale and affirmatively answered questions by the study population in Zanzibar (*N* = 196). During the last 12 months, was there a time when . . .

No	Food Insecurity Experience Scale Questions	*N*	%
1	You were worried you would run out of food because of a lack of money?	112	57.1
2	You were unable to eat healthy and nutritious food because of a lack of money?	134	68.4
3	You ate only a few kinds of foods because of a lack of money?	144	73.5
4	You had to skip a meal because there was not enough money to get food?	100	51.0
5	You ate less than you thought you should because of a lack of money?	117	59.7
6	Your household ran out of food because of a lack of money?	103	52.6
7	You were hungry but did not eat because there was not enough money for food?	76	38.8
8	You went without eating for a whole day because of a lack of money?	51	26.0

3.2. Correlates of Food Consumption and Food Insecurity

Households with a higher-educated HH had a lower chance of reporting severe food insecurity (OR 0.53; 95% CI 0.28–1.08) compared to those with lower-educated HH (Table 4). Those HH married in monogamy had a higher chance of reporting acceptable food consumption (OR 1.71; 95% CI 0.55–5.38) but at the same time a higher chance of severe food insecurity (OR 1.83; 95%CI 0.55; 6.08) compared to those HH not married (single, widowed, cohabitating or divorced) (Table 4). Polygamous households had a higher chance of severe food insecurity (OR 3.95; 95% CI 1.17–13.4) and also reported higher chance for acceptable food consumption (OR 1.78; 95% CI 0.54–5.83) compared to those not married. Larger households had a higher chance of severe food insecurity (OR 2.44; 95% CI 1.16–5.13) than smaller households, while wealthy households had a lower chance of severe food insecurity (OR 0.52; 95% CI 0.25–1.11) than poor households.

Table 4. Associations of socioeconomic and demographic correlates of 196 households with food consumption (Model 1) and food insecurity (Model 2) in terms of odds ratios (OR) and 95% confidence intervals (CI) as well as model fit (generalized chi-square/degrees of freedom), respectively.

	Model 1: Food Consumption (Ref: Poor)		**Model 2: Food Insecurity (Ref: Mild to Moderate)**	
Model fit	χ^2/DF	0.87	χ^2/DF	0.86
Between Shehia variance (SE)		0.48 (0.38)		0.37 (0.38)
	OR	**(95% CI)**	**RR**	**(95% CI)**
Gender (ref: female)	1.76	(0.75–4.11)	1.65	(0.68–4.01)
Marital status of HH (ref: not married)				
monogamous	1.71	(0.55–5.38)	1.83	(0.055–6.08)
polygamous	1.78	(0.54–5.83)	3.95	(1.17–13.4)
Education (ref: low)	1.36	(0.69–2.70)	0.53	(0.26–1.08)
Number of jobs (ref: no job)	1.22	(0.59–2.50)	0.58	(0.28–1.22)
Area of residence (ref: rural)	2.08	(0.85–5.10)	0.64	(0.24–1.70)
Household size (ref: small)	1.02	(0.51–2.05)	2.44	(1.16–5.13)
Wealth (ref: poor ≥ 5)	1.35	(0.64–2.83)	0.52	(0.25–1.11)
Number of vehicles (ref: none)	1.04	(0.42–2.57)	0.78	(0.32–1.89)
Food access (ref: poor ≤ 6)	1.56	(0.79–3.10)	0.69	(0.33–1.43)

3.3. Role of Food Access on the Correlates, Food Consumption and Food Insecurity

There were few relevant changes in the chances observed in the interaction of food access with gender, marital status of HH, number of jobs, and wealth on both food consumption and food insecurity. However, urban households with good FA showed a higher chance of acceptable food consumption compared to rural households with poor FA (Table 5, Model 3e). Households with no vehicle had a higher chance of acceptable food consumption if they had good FA compared to those with poor FA (OR 6.21; 95% CI 1.20–32.3). However, having at least one vehicle tentatively increased the chance of having acceptable food consumption for both good and poor FA (OR 2.17; 95% CI 0.68–6.87; OR 1.83; 95% CI 0.59–5.71, respectively) (Model 3h).

In comparison to households with low-educated HH and poor FA, we observed a lower chance of severe food insecurity in households with higher-educated HH either with good FA (OR 0.42; 95% CI 0.15–1.17) or poor FA (OR 0.40; 95% CI 0.16; 1.02) and in households with lower-educated HH and good FA (OR 0.49; 95% CI 0.18–1.30) (Model 4c). Considering poor FA, larger households (six or more members) had a higher chance of severe food insecurity (OR 3.42; 95% CI 1.29–9.10) compared to smaller households (Model 4f).

Table 5. Results of the multilevel logistic regressions in terms of odds ratios (OR) and 95% confidence limits as well as model fit (generalized chi-square/degrees of freedom) to investigate the interaction of food access with socioeconomic and demographic correlates on food consumption (Model 3a–h) and food insecurity (Model 4a–h), each adjusted for the remaining correlates.

Model	Covariate	Food Access	Model 3: Food Consumption (Ref: Poor)					Model 4: Food Insecurity (Ref: Mild to Moderate)				
			Ref: *N* (%)	OR	(95% CI)	Between Shehia Variance (SE)	χ^2/DF	Ref: *N* (%)	OR	(95%CI)	Between Shehia Variance (SE)	χ^2/DF
a	**Gender**											
	Male	Good access	34 (55.7)	3.03	(0.96–9.62)	0.48 (0.38)	0.88	41 (67.2)	0.85	(0.29–2.53)	0.41 (0.39)	0.87
	Male	Poor access	38 (61.3)	2.26	(0.73–7.00)			39 (62.9)	0.99	(0.36–2.78)		
	Female	Good access	19 (65.5)	2.24	(0.66–7.66)			24 (82.8)	0.44	(0.12–1.61)		
	Female	Poor access	37 (84.1)	1.00				30 (68.2)	1.00			
b	**Marital status** [a]											
	Married	Good access	43 (55.8)	1.96	(0.49–7.88)	0.50 (0.39)	0.85	53 (68.8)	1.67	(0.43–6.39)	0.39 (0.39)	0.87
	Married	Poor access	58 (68.2)	1.09	(0.28–4.25)			53 (62.4)	2.28	(0.63–8.20)		
	Not married	Good access	10 (76.9)	0.62	(0.09–4.20)			12 (92.3)	0.44	(0.04–5.01)		
	Not married	Poor access	17 (81.0)	1.00				16 (76.2)	1.00			
c	**Education**											
	High	Good access	28 (58.3)	2.21	(0.82–5.98)	0.49 (0.39)	0.87	37 (77.1)	0.42	(0.15–1.17)	0.38 (0.38)	0.88
	High	Poor access	31 (60.8)	2.09	(0.80–5.48)			38 (74.5)	0.40	(0.16–1.02)		
	Low	Good access	25 (59.5)	2.53	(0.91–7.06)			28 (66.7)	0.49	(0.18–1.30)		
	Low	Poor access	44 (80.0)	1.00				31 (56.4)	1.00			
d	**Number of jobs**											
	One or more	Good access	36 (60.0)	2.05	(0.80–5.24)	0.55 (0.40)	0.86	42 (70.0)	0.44	(0.17–1.13)	0.50 (0.42)	0.83
	One or more	Poor access	31 (63.3)	1.95	(0.73–5.17)			35 (71.4)	0.36	(0.14–0.95)		
	No Job	Good access	17 (56.7)	2.81	(0.96–8.25)			23 (76.7)	0.32	(0.10–1.01)		
	No Job	Poor access	44 (77.2)	1.00				34 (59.6)	1.00			
e	**Area of residence**											
	Urban	Good access	6 (35.3)	5.48	(1.42–21.2)	0.46 (0.38)	0.88	14 (82.4)	0.44	(0.09–2.08)	0.39 (0.38)	0.87
	Urban	Poor access	17 (65.4)	1.21	(0.39–3.71)			18 (69.2)	0.62	(0.19–1.96)		
	Rural	Good access	47 (64.4)	1.16	(0.53–2.51)			51 (69.9)	0.70	(0.32–1.53)		
	Rural	Poor access	58 (72.5)	1.00				51 (63.8)	1.00			
f	**Household size**											
	Large	Good access	23 (52.3)	1.56	(0.59–4.12)	0.46 (0.38)	0.88	30 (68.2)	1.56	(0.54–4.48)	0.38 (0.38)	0.87
	Large	Poor access	37 (69.8)	0.70	(0.26–1.86)			29 (54.7)	3.42	(1.29–9.10)		
	Small	Good access	30 (65.2)	1.08	(0.41–2.84)			35 (76.1)	1.15	(0.41–3.22)		
	Small	Poor access	38 (71.1)	1.00				40 (75.5)	1.00			
g	**Wealth**											
	Wealthy	Good access	28 (53.8)	2.21	(0.78–6.28)	0.48 (0.38)	0.87	40 (76.9)	0.38	(0.13–1.09)	0.43 (0.40)	0.86
	Wealthy	Poor access	39 (63.9)	1.59	(0.57–4.48)			43 (70.5)	0.42	(0.16–1.14)		
	Poor	Good access	25 (65.8)	1.90	(0.63–5.71)			25 (65.8)	0.51	(0.18–1.47)		
	Poor	Poor access	36 (80.0)	1.00				26 (57.8)	1.00			

Table 5. *Cont.*

Model	Covariate	Food Access	Model 3: Food Consumption (Ref: Poor)					Model 4: Food Insecurity (Ref: Mild to Moderate)				
			Ref: *N* (%)	OR	(95% CI)	Between Shehia Variance (SE)	χ^2/DF	Ref: *N* (%)	OR	(95%CI)	Between Shehia Variance (SE)	χ^2/DF
h	**Number of Vehicles**											
	At least one	Good access	48 (60.8)	2.17	(0.68–6.87)	0.44 (0.38)	0.89	56 (70.9)	0.51	(0.18–1.43)	0.38 (0.38)	0.86
	At least one	Poor access	49 (66.2)	1.83	(0.59–5.71)			50 (67.6	0.63	(0.24–1.69)		
	None	Good access	5 (45.5)	6.21	(1.20–32.3)			9 (81.8)	0.31	(0.05–2.06)		
	None	Poor access	26 (81.3)	1.00				19 (59.4)	1.00			

[a] Two categories for marital status of HH were used (1 = not married (single, widow, divorce, cohabitation) 2 = married (monogamous or polygamous)).

4. Discussion

This exploratory study aimed at adding to the on-going debate on how good FA may help to improve the nutrition situation of the Zanzibar population. We observed that poor FA, poor food consumption, and food insecurity are a problem in many Zanzibari households. Poor FA was more prevalent in households with poor food consumption and severe food insecurity. In particular, polygamous households and larger households had a higher chance of severe food insecurity. Good FA increased the chance of acceptable food consumption for urban households and households with no vehicle, whereas poor FA increased the chance for severe food insecurity for larger households.

4.1. Proportions of FCS and FIES in the Study Population

The proportion of households with acceptable food consumption was about 35% in the present study. This is lower than reported in Ethiopia (73%) [29] and in the Nyarugusa refugee camp in Tanzania (86%) with a sample of 343 households in a WFP/United Nations High Commissioner for Refugees (UNHCR) study [30]. Food consumption was assessed using comparable instruments in the present study and in the UN World Food Programme Study [23]; thus, the higher proportions in the Nyarugusa camp could have been due to the fact that 83% of the households' main source of food was from food aid, unlike in Unguja Island, where households relied mostly on purchase and on their own production. The overall proportion of mild to moderate food insecurity in our study population was about 68%, slightly higher than the 49% observed in Burkina Faso among 330 surveyed households [31], and doubles that in Ethiopia (34%) [32]. This survey was conducted during the short-rainy season (October–December 2013), which is a time for sowing and growing of food products and when most household stocks are depleted [33]. This may have contributed to the relatively low proportions of households with acceptable food consumption. Still, the proportion of households with experienced mild to moderate food insecurity was higher compared to other household surveys, which were also conducted during the lean seasons [29,31,32,34]. More than three quarters of the households in our study resided in the rural area and hence depended mostly on own food production, and food products grown in the rainy season are harvested between January and February. A survey conducted in Burkina Faso confirmed the seasonal effects on food security of 1056 households with a lower food security during the lean season compared to the post-harvest season [34]. Hence, data collection should also be conducted during the post-harvest season in order to gain insight into FCS and FIES when food availability improves on Unguja Island.

4.2. Role of Food Access on the Correlates, Food Consumption and Food Insecurity

In the present study, higher education level of the HH seemed to influence the level of food consumption and food insecurity of the households with poor FA, agreeing with findings from Rwanda [35] and Uganda [36], reflecting that "some level of education is important to household food security". It is assumed that a literate HH has a greater capacity of adapting to improved technologies and coping strategies, thus increasing production/food supply in the household [16]. The lower chance for severe food insecurity in households with higher-educated HH and good FA, higher-educated HH and poor FA, and lower-educated HH and good FA indicated that education level of the HH as well as FA both played a comparable role in impacting the food insecurity status of the household.

The fact that in this study, larger households had higher chances for severe food insecurity than smaller households may be explained by the fact that smaller household sizes are generally better manageable in terms of food demand and supply. The latter can be improved through own production, which increases food consumption and decreases food insecurity as also reported in other studies [18,37]. In contrast to our findings, studies from Niger and Nigeria observed a decreasing likelihood of a household being food-insecure with an increasing household size [38]. However, to estimate the effect of household size on food insecurity is challenging, as this would require verifying numerous other factors such as the number of all active members in the household (contributors of income or food), income sources (salary), and expenditure on food. While the number of jobs of the HH showed no effect on food insecurity, wealthier households, on the other hand, revealed a lower chance of having severe food insecurity compared to poor households. Interestingly, our results showed that larger households with poor FA had a higher chance for severe food insecurity compared to smaller households, while those with good FA only had a smaller chance for severe food insecurity compared to small households with poor FA, this further confirms the role FA played in impacting food insecurity in the study population. Studies investigating the role of FA on food consumption and food insecurity in Sub-Saharan Africa are scarce, and more research is advisable.

In our study, households with polygamous HH had a higher chance for of severe food insecurity than households with not married (e.g., widowed or divorced) HH. While this is in line with previous findings from Tanzania mainland [39], other studies reported contrasting findings [40,41]. The latter postulated that the large number of individuals in polygamous households means that a great number of individuals can provide financial and labor support among each other, thus reducing the chance of having food insecurity. However, these studies compared polygamous households against monogamous households. When we compared monogamous against unmarried households, we observed a relatively lower chance of experiencing severe food insecurity. This is supporting our findings that larger households were more likely to be food-insecure compared to smaller households.

The finding that urban households with good FA experienced a higher chance of acceptable food consumption than rural households with poor FA may be explained by the good infrastructure in urban areas, which enables good accessibility for foods and may potentially enhance the food diversity of households. The good infrastructure includes factors such as the quality of roads or market density, which facilitate food distribution and transport into the communities. Studies in Malawi and Kenya [42,43] also reported that food insecurity for rural households was affected by long distance to the market and poor market access. Furthermore, in Malawi, the distance to the market was reported to affect food consumption for both rural and urban households [42]. The fact that in our study, even households without a vehicle had a higher chance of acceptable food consumption when they had good FA compared to those with poor FA indicates the importance of other aspects of the FA—in addition to infrastructure—such as borrowing foods, receiving foods as a gift, and own food production or animal rearing. The interplay of multiple factors facilitating food accessibility should be considered in future intervention studies.

4.3. Strengths and Limitations

This exploratory study provides valuable data on the interplay of food access, socioeconomic and demographic correlates with food consumption and food insecurity of Zanzibari households. Even though our study was conducted during the short-rainy season, which made it difficult to have access to some of the villages, an important strength was the overall high proportion of households that participated in the study. Further, the highly standardized study protocol using partly validated and pretested methods and instruments is a clear strength of the study. When comparing the study characteristics such as HH demography (gender, marital status, education level, occupation), household demography (rural/urban, household size), and the socioeconomic status of the household of the full survey sample and the sample presented in this study sample, no substantial differences were observed (results not shown). Thus, a selection bias can be ruled out.

The study, however, has limitations. Firstly, the FIES was explicitly developed for cross-cultural comparability and assesses correlates of food insecurity across different areas that have the same climatic or agricultural calendar [44]. We, however, conducted our study only in Unguja Island and hence have no basis for a comparison with other Zanzibari islands such as Pemba Islands, or with the population of Mainland Tanzania. As household information was based on self-reports, social desirability could have influenced the responses given. The survey was conducted during October–December, which is the time of the year when most household stocks are depleted (lean season) [33]; this may have affected our results on the food consumption and food insecurity situation of the households and must be acknowledged as a limitation. Further, the collection of cross-sectional data means that effects of seasonal variations could not be investigated. To overcome this limitation, it would be advisable to collect longitudinal data.

One major limitation we like to address is that the overall study was planned, powered, and conducted to estimate the prevalence of malnutrition in the Zanzibari population [22]. However, with this study, we intended to explore important household survey data on a broader level even though for this particular approach, the sample size was underpowered. Nevertheless, the data are a useful source for exploring the role of FA in the association between sociodemographic household factors with food consumption and food insecurity. Findings from this study will add knowledge and inform the development of intervention strategies and policies aiming at improving food consumption and food security in Zanzibar. Still, more research with a larger sample size is advisable.

5. Conclusions

Based on our findings, poor access to food may be seen as a modifiable factor for food consumption and perceived food insecurity in Zanzibari households, in particular for the association with educational level and household size. To improve food and nutrition security in Zanzibar, implementation of policies and programs that address education activities and different forms of practical coping strategies, such as efficient food storage techniques and home gardening, in their agendas are needed, particularly in rural areas. In parallel, strategies should consider improvement of infrastructure to facilitate distribution of produce within the rural–urban areas, as well as education campaigns on food quality and utilization, emphasizing on the importance of food group and balanced diets.

Ethics Approval and Consent to Participate: Ethical approval was obtained from the Ethics Committees of the University of Bremen in Germany with a reference number 06-3 and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee in Zanzibar, Tanzania with a reference number ZAMREC/0001/AUGUST/013. Written informed consents were taken from all participants and parents/guardians gave a written informed consent for their children. The consent forms were approved by the Institutional Ethics Committee.

Author Contributions: This manuscript represents original work that has not been published previously and is currently not considered by another journal. The authors' responsibilities were as follows: A.H. and M.A.N. had the idea of the analysis; A.H., M.A.N., S.K., and M.S. were responsible for data collection. M.A.N. and C.B. conducted statistical analyses; M.A.N. and C.B. did the analysis and data interpretation; M.N. wrote the manuscript and had primary responsibility for final content and submitting the manuscript for publication; M.A.N., S.K., M.S., C.B., and A.H. were responsible for critical revisions and final approval of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

FA	Food Access
FANTA	Food and Nutrition Technical Assistance
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
FIES	Food Insecurity Experience Scale
GLIMMIX	Generalized Linear Mixed Models
HH	Head of Household
ISCED	International Standard Classification of Education
SNNPR	South Nation's, Nationalities and Peoples Region
SSA	Sub-Saharan Africa

SUTAS	Sustainable Use of Tropical Aquatic Systems
TDHS	Tanzanian Demographic and Health Survey
UNHCR	United Nations High Commissioner for Refugees
WFP	World Food Programme
WHO	World Health Organization

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Publication 3

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Association between cardiometabolic risk factors and body mass index, waist circumferences and body fat in a Zanzibari cross-sectional study

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ABSTRACT

Objectives To determine the prevalence of obesity indices (body mass index (BMI), waist circumference (WC), body fat per cent (BF%)) and cardiometabolic risk factors. To investigate the association between obesity indices and cardiometabolic risk factors in a Zanzibari population.

Designs Cross-sectional study.

Settings Participants randomly selected from 80 Shehias (wards) in Unguja, Zanzibar in 2013.

Participants A total of 470 participants between 5 and 95 years were examined. Data on socioeconomic status, area of residence, anthropometry and venous blood were collected. Associations between obesity indices and cardiometabolic risk factors were investigated using multilevel logistic regression analyses in two steps: first, each obesity indicator was tested independently; second, all indicators combined in one model were tested for their association with cardiometabolic risk factors.

Results The proportion of overweight/obese individuals was 26.4%, high WC (24.9%) and high BF% (31.1%). Cardiometabolic risk factors with highest prevalence of abnormal values included hypertension (24.5%), low high-density lipoprotein cholesterol (HDL-C) (29.4%), high low-density lipoprotein cholesterol (LDL-C) (21.3%) and high glycated haemoglobin (HbA1c) (19.1%). Obesity and hypertension increased with age, and were most prevalent in participants aged 45 years and above. Low HDL-C was most prevalent among participants aged ≥18 to <45 years, while high LDL-C was more prevalent in those above 45 years. High WC and high BF% were associated with high levels of LDL-C (OR=2.52 (95% CI 1.24 to 5.13), OR=1.91 (95% CI 1.02 to 3.58), respectively). Additionally, BMI and WC were associated with high levels of HbA1c (OR=2.08 (95% CI 1.15 to 3.79), OR=3.01 (95% CI 1.51 to 6.03), respectively). In the combined regression model, WC was associated with higher chances for hypertension (OR=2.62 (95% CI 1.14 to 6.06)) and for high levels of HbA1c (OR=2.62 (95% CI 1.12 to 6.15)).

Conclusion High BMI, WC and BF% were strongly associated with hypertension, with individuals with high WC being twice more likely to have hypertension; this calls for early and effective screening strategies for this study population.

Strengths and limitations of this study

- ► This is the first study to report the associations between obesity indices and cardiometabolic risk factors in Zanzibar.
- ► The household-based approach, which involved visiting the families in the home setting, resulted in a high individual response rate, thus minimising risk of selection bias.
- ► The cross-sectional design prevents us from drawing conclusions regarding the impact of changes in obesity indices on risk factors.
- ► Bioelectrical impedance analysis was used to estimate body fat percentage, which might have underestimated adiposity in children.

INTRODUCTION

Worldwide, cardiovascular diseases (CVDs) are the leading cause of death,[1] and are emerging as a notable public health problem in sub-Saharan African countries.[2] These countries are undergoing epidemiological transitions from communicable to non-communicable diseases (NCDs) that have been closely linked to increased urbanisation and rural-urban migration, which has led to unhealthy behaviours, including poor dietary habits and sedentary lifestyles.[2 3] According to the International Diabetes Federation (IDF), about 12 million people in Africa are estimated to have type 2 diabetes mellitus,[4] with the prevalence ranging from 1% in rural Uganda to 12% in urban Kenya.[5 6] Overweight and obesity have been found to be modifiable risk factors for cardiometabolic and other chronic diseases[7] including hypertension,[8] diabetes[9] and dyslipidemia.[10] The third report of the National Cholesterol Education Programme-Adult treatment Panel (NCEP-ATP III) also identified central obesity, dyslipidemia (hypertriglyceridemia and low levels of high-density lipoprotein cholesterol (HDL-C)), impaired glucose tolerance and elevated blood pressure as cardiometabolic risk factors.[11]

Multiple obesity indices such as body mass index (BMI), waist circumference (WC), body fat per cent (BF%) and waist-to-hip ratio have been widely used to screen individuals for cardiometabolic risk in clinical and research settings[12–14] due to their low cost and ease of administration. The performance of anthropometric indices may however vary according to different factors, including ethnicity, age, geographical area and population.[13 15] BMI, which is based on weight and height, is the most widely used marker to assess body mass. In children and adolescents, the z-scores are used to classify obesity status,[16] which is linked to metabolic risk, for example, in South African youth.[17] However, BMI does not distinguish well between lean mass and fat mass.[18] In contrast, WC is a measure of total body and abdominal fat accumulation and is better correlated with visceral adipose tissues than BMI. The correlation on the other hand varies significantly across ethnicities.[19 20] Another approach for measuring body fat is through bioelectrical impedance analysis (BIA), which has also been done in several epidemiological studies.[21] The use of different anthropometric measurements might also provide complementary information which can be used to aid screening for cardiometabolic risk in different population settings.[22 23]

Few studies have investigated the performance of different obesity indices in association with cardiometabolic risk factors in sub-Saharan African populations.[2 7 18] Data from mainland Tanzania have shown an increasing prevalence of overweight and obesity in urban, peri-urban and rural areas.[24] However, there is still a dearth of population-based studies investigating the associations of cardiometabolic risk factors with obesity indices in Tanzania mainland and Zanzibar. To help fill this gap, this study uses cross-sectional data of 470 individuals between 5 and 95 years who were examined in 2013 in Unguja Island, Zanzibar, to describe the prevalence of overweight/obesity and cardiometabolic risk factors in three age groups (≥5 to <18 years, ≥18 to <45 years and 45 years and above). The aim of the study was to identify vulnerable groups in the Zanzibari population with respect to cardiometabolic risk. Consequently, we investigated the association of BMI, WC and BF% with cardiometabolic risk factors (hypertension, total cholesterol, triglycerides, HDL, low-density lipoprotein (LDL), glycated haemoglobin (HbA1c), fasting plasma glucose and homeostasis model assessment of insulin resistance (HOMA-IR)). We considered the three obesity indices independently as well as combined, thereby reflecting different aspects of body composition.

SUBJECTS AND METHODS

Study population and design

We conducted a cross-sectional survey from September to December 2013 in a representative population sample in Unguja Island, Zanzibar. A total of 239 households were randomly selected and all household members were invited for the examination. As we also aimed to identify vulnerable groups within the families, we included young children and the elderly, who both normally depend on the family food environment. A two-stage sampling approach was used: (1) from a list of all 213 Shehias (wards), 80 Shehias were randomly selected; (2) households were randomly selected based on the Shehias' registration records. Participation agreement was requested from all members of a household. A total of 1443 family members agreed to participate and completed anthropometric and blood pressure measurements, as well as interviewer-administered questionnaires. Venous blood was also collected. The subgroup examinations are described in detail below. The complete description of the study design and methods has been described in detail elsewhere.[25] The study was performed according to the Helsinki Declaration and the study protocol was evaluated and approved by the Ethics Committees of the University of Bremen and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee. All participants gave written informed consent and parents/guardians consented on behalf of their children in writing.

Patient and public involvement

During the development of the survey tools, measurements and the study protocol, a meeting was held with the local partners, government officials and researchers in Zanzibar to discuss the needs and gaps of the nutrition and health survey planned in Zanzibar. The documents and instruments were then modified according to the needs of the Zanzibari population as recommended in the meeting.

A year after the survey, preliminary results on the major health outcomes and related risk factors were presented and discussed during 2 days feedback workshop with the administrative leaders (e.g., Shehas, district commissioners), stakeholders (from health services, government officials, food safety) and our local partners in Zanzibar (academics and research). Each Sheha was handed a poster of the preliminary results, which was then displayed at their local offices for all Shehia members to see. District commissioners received a summary report on all Shehias of their districts. The preliminary results were further publicised on TV and print media. The same group of workshop participants was invited to a further workshop in 2018, whose aim was to identify target populations and channels for future nutrition education to address the aetiology and prevention of NCDs in the Zanzibari population, taking into consideration the survey results presented also in this study.

This observational epidemiological study examined participants in their home environment and did not enrol clinical patients.

Questionnaires and anthropometric measurements

Questionnaires were developed in English, translated into Swahili and then back translated to control for translation errors. Trained field staff collected the survey information. Parents reported their age and sex, as well as that of their children. Age was grouped into three categories ≥5 to <18 years, ≥18 to <45 years and 45 years and above. In addition, parental highest educational level according to the International Standard Classification of Education (ISCED)[26] was used as a proxy indicator for socioeconomic status of the family. Education was categorised into low education (no education and primary school) and high education (secondary school and above). To determine participants' area of residence, information on region, district and Shehia (the smallest administrative unit in Zanzibar) was recorded and two categories for area of residence were developed (urban and rural). Utilisation of medication was also documented in the questionnaire. Regarding medication for obesity-related conditions, participants reported use of hypertension medication but not of diabetes or dyslipoproteinemia medication. Hence, the variable was later categorised as 'hypertension medication' and 'other medication' (eg, antimalaria therapy or antipyretic products). To ensure a high quality of data collection, this study used proven examination methods and laboratory standards.[27 28] All anthropometric measurements and physical examinations were adopted from the Identification and prevention of dietary- and lifestyle induced health effects in Children and infants (IDEFICS) study and conducted following standardised procedures.[29 30] Measurement of body weight was carried out to the nearest 0.1 kg and BF% was determined using the BIA method using an electronic scale (TANITA BC-420 SMA, Germany). Height was measured using a SECA 213 stadiometer, UK, and WC was measured midway between the lowest rib and the iliac crest, using an inelastic measuring tape (SECA 201). For all measurements, participants wore light clothing. The measures were recorded to the nearest 0.1 cm. The complete description of the anthropometric measurements of the study is described elsewhere.[25]

For children and adolescents, BMI was calculated as kg/m^2 and then transformed to age-specific and sex-specific z-score and percentiles. Thereafter, categories for overweight (BMI between >75th and <95th percentile) and obesity (BMI >95th percentile) were built according to the WHO centile curves.[16 31] For adults, overweight/obesity was defined as BMI ≥25 kg/m^2 as recommended by WHO.[32] For statistical analysis, the BMI categories were merged into two: (1) underweight/normalweight (≤ 75th percentile for children and adolescents and <25 kg/m^2 for adults) and (2) overweight/obesity (>75th percentile and ≥25 kg/m^2). Regarding WC, high abdominal obesity was defined as WC ≥90th percentile for children below 10 years[33]; WC ≥90th percentile for adolescents aged 10 to <16 years and WC >94 cm for men and >80 cm for women for participants 16 years and older, as recommended by the IDF.[34] As recommended by McCarthy *et al*,[35] for boys and girls below 18 years, high BF% was set at ≥85th percentile. For adults above 18 years, high BF% was defined as ≥20% for men and ≥32% for women.[36] The cut-offs and references are listed in table 1.

Cardiometabolic risk factors

All blood samples were drawn after overnight fasting and were collected from all eligible participants over 5 years of age by venepuncture.[37] To reduce pain, children below 10 years of age were given a local anaesthetic plaster before blood drawing, which motivated the children to participate. Before blood drawing, the procedure was once again explained to all participants in easy language and they were informed that they still could refuse to participate. For children weighing 10 kg, the blood collection was restricted to 1%, corresponding to approximately 8 mL. For healthy, non-pregnant adults weighing at least 50 kg, a maximum of 20.5 mL venous blood was drawn. Collection, processing and storage of blood samples are described elsewhere.[25]

Metabolic parameters were categorised for investigating the prevalence of cardiometabolic disorders in the study population. Due to the wide range of age groups in this study population, different cardiometabolic risk definitions and cut-offs were used (table 1). Cardiometabolic risk for children between 5 and 10 years was defined according to age-specific and sex-specific cut-offs. The parameters, including hypertension (systolic blood pressure and diastolic blood pressure), blood lipids (high total cholesterol (TC), high triglycerides (TG), LDL cholesterol (LDL-C) and HDL-C), blood glucose/insulin (HOMA-IR and elevated fasting plasma glucose (FPG), were defined according to the IDEFICS study.[38–40] HbA1c was defined according to Rödöö *et al*[41] for children under 17 years. For children and adolescents between 10 and 16 years, hypertension was defined according to age-specific and sex-specific cut-offs as recommended[42]; for adolescents and adults >16 years hypertension was defined as recommended.[43] Blood lipids (TC and LDL-C) were defined according to the NCEP[11] and TG, HDL-C and FPG according to IDF.[34] HbA1c for participants >17 years was defined according to Stern *et al*[44] and insulin resistance was estimated as HOMA-IR according to the reference value of HOMA-IR as recommended by Shashaj *et al*.[45] In the present study, the 75th percentile cut-off was used for children and adolescents from 10 to 17 years. For participants >17 years, HOMA-IR was defined according to von Eyben *et al*.[46] HOMA-IR was calculated from glucose (mmol/L)) and insulin (μU/mL) concentrations using the formula: HOMA-IR=(fasting insulin×fasting glucose/22.5).[47]

Inclusion criteria for study sample

Of 1443 individuals who participated in this study, 1314 fulfilled the inclusion criteria (age, sex, weight, height) for the overall study analysis. Of the 1314 participants, 1234 provided complete WC and BF% measurements. Among these, 557 provided complete blood samples for the cardiometabolic risk analysis and only 505 were on fasting status. To reduce bias while estimating mean and

Table 1 Cardiometabolic risk definitions and references

Age group	Obesity indices and blood pressure	Blood lipids	Blood glucose/insulin
Children: ≤10 years	BMI ≥75th percentile*	TC ≥90th percentile†	HbA1c ≥97.5th percentile‡
	WC ≥90th percentile†	TG ≥90th percentile†	HOMA-IR ≥95th percentile†
	BF% ≥85th percentile§	HDL-C ≤10th percentile†	FPG ≥95th percentile†
	SBP ≥90th percentile or DBP ≥90th percentile†	LDL ≥90th percentile†	
Adolescents: >10 to <16 years	BMI ≥75th percentile*	TC ≥5.2 mmol/L¶	HbA1c ≥97.5th percentile‡
	WC ≥90th percentile**	TG ≥1.7 mmol/L**	HOMA-IR ≥75th percentile††
	BF% ≥85th percentile§	HDL-C <1.03**	FPG ≥5.6 mmol/L**
	SBP≥140 mm Hg or DBP ≥90 mm Hg‡‡	LDL ≥3.4 mmol/L¶	
Adults: ≥16 years	BMI ≥25 kg/m^2*	TC ≥5.2 mmol/L¶	HbA1c ≥6.1%§§
	WC ≥94 cm male, ≥80 cm female**	TG ≥1.7 mmol/L**	HOMA-IR>4.65 or HOMA-IR>3.60 and BMI >27.5 kg/m^2 ¶¶
	BF% ≥20% male and ≥32% female***	HDL-C <1.03 male, <1.29 female**	FPG ≥5.6 mmol/L**
	SBP≥140 mm Hg or DBP ≥90 mm Hg	LDL ≥3.4 mmol/L¶	

*WHO.
†IDEFICS study.
‡Rödöö *et al*.[41]
§McCarthy *et al*.[35]
¶National Cholesterol Education Programme.
**International Diabetes Federation.
††Shashaj *et al*[45] for children and adolescents under 17 years.
‡‡National Institute of Health third and seventh report, respectively.
§§Stern *et al*[44] for adults above 17 years.
¶¶von Eyben *et al*.[46]
***Gallagher *et al*.[36]
BF%, body fat per cent; BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HbA1c, glycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

SD in the regression analysis, we excluded the top 1% of individuals with extremely high values for cardiometabolic risk and obesity indices, leaving us with a complete sample of 470 participants for the analysis.

Statistical analysis

Descriptive analysis was conducted to calculate the mean SD and range (minimum, maximum) for continuous variables, as well as the distribution of the categorical data in N and percentages (%). As part of the regression analysis, we tested the necessary assumptions in terms of symmetry and normality using residual plots and Q-Q plots. Mixed logistic regression models were used to analyse the association between obesity indices and cardiometabolic risk factors. In addition, potential clustering within households was considered in terms of a random intercept. Following the hierarchy of the municipal structure in Zanzibar, we conducted sensitivity analysis modelling either Shehias or households within Shehias as a random intercept in the models. Since the results of the models only showed marginal differences, we only considered the household as a random intercept in our analyses. First, mixed logistic regression models were conducted to estimate the association between each of the three obesity indicators (BMI, WC and BF%) as exposure variables and each of the eight risk factors (hypertension, TC, TG, HDL-C, LDL-C, HbA1c, FPG and HOMA-IR) as dependent variables, in terms of ORs and 95%CIs. Since BMI, WC and BF% are inter-related, the strongest relationship with cardiometabolic risk factors was investigated by conducting mixed logistic regression models. This was done by estimating the association (ORs and 95% CIs) between all three obesity indices as dependent variables in one model and each of the eight risk factors as outcome variables. All models were adjusted for potential confounders and covariates such as gender, age, education level (ISCED), area of residence and utilisation of hypertension medication. Statistical analysis was performed using SAS V.9.3 (SAS Institute, Cary, North Carolina, USA); mixed logistic regression models were conducted based on the GLIMMIX procedure; statistical significance was set at α=0.05.

RESULTS

Distribution of obesity and cardiometabolic risk and characteristics of the study population by age groups (n=470)

The mean age was 29 (±18) years, with the highest proportion being in the age group (≥18 to <45 years) (table 2). The overall mean values for BMI, WC and BF% were as follows: BMI 22 kg/m^2 (±5.2), WC 75 cm (±16)

Table 2 Distribution of obesity and cardiometabolic risk in the study population (n=470) by age group (means and SD)

	≥5 to <18 years (n=165)		≥18 to <45 years (n=195)		45+ years (n=110)		Total (n=470)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Age (years)	12 (3.4)	4.9–18	28 (8.1)	18–44	57 (9.8)	45–95	29 (18)	4.9–95
BMI (kg/m^2)	17 (3.4)	11–34	23 (4.5)	16–37	26 (5.7)	15–49	22 (5.7)	11–49
WC (cm)	61 (11)	12–103	79 (12)	37–111	88 (0.2)	35–126	75 (16)	12–126
BF (%)	15 (7.0)	1.6–45	23 (11)	3.0–53	28 (10)	6.2–53	22 (11)	1.6–53
DBP (mm Hg)	67 (9.8)	44–97	76 (10)	53–126	88 (15)	62–140	75 (14)	44–140
SBP (mm Hg)	110 (13)	69–152	123 (16)	72–197	150 (28)	100–229	125 (24)	69–229
TC (mmol/L)	3.7 (0.7)	1.8–5.9	3.9 (0.8)	2.1–6.0	4.2 (0.8)	0.2–5.9	3.9 (0.8)	0.2–6.0
TG (mmol/L)	0.8 (0.3)	0.3–2.5	0.9 (0.4)	0.0–2.6	1.0 (0.4)	0.4–2.7	0.9 (0.4)	0.0–2.7
HDL-C (mmol/L)	1.4 (0.5)	0.7–3.3	1.5 (0.5)	0.6–3.7	1.4 (0.4)	0.6–3.6	1.4 (0.5)	0.6–3.7
LDL-C (mmol/L)	2.3 (0.9)	0.0–5.0	2.5 (0.9)	0.7–5.1	3.0 (1.0)	0.6–5.1	2.5 (1.0)	0.0–5.1
HbA1c (%)	5.7 (0.5)	4.2–8.5	5.6 (0.6)	3.9–9.4	6.0 (0.8)	4.4–10	5.8 (0.6)	3.9–10
Serum insulin (mmol/L)	4.3 (3.1)	0.4–18	4.8 (2.8)	0.8–17	3.6 (2.3)	0.4–17	4.4 (2.8)	0.4–18
FPG (mmol/L)	4.9 (0.8)	2.0–7.7	4.8 (0.9)	0.5–9.4	5.1 (1.3)	0.2–13	4.9 (1.0)	0.2–13
HOMA-IR	1.0 (0.7)	0.1–4.6	1.1 (0.7)	0.0–4.3	0.9 (0.6)	0.0–4.0	1.0 (0.7)	0.0–4.6

BF%, body fat per cent; BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HbA1c, g lycated haemoglobin; HDL, high-density lipoprotein; HOMA-IR, homeostasis model assessment of insulin resistance; LDL, low-density lipoprotein; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

and BF% 22% (±11). The mean BMI of 26 kg/m^2 (±5.7) for participants >45 years was slightly higher than normal, indicating overweight. Mean diastolic blood pressure was in the normal range for all the age groups, but a higher mean value of systolic blood pressure, 150 mm Hg (±280) was observed among participants >45 years. The mean values of most of the variables showed an increase with age group, except for HDL-C and diabetes markers (HbA1c, serum insulin, plasma glucose and HOMA-IR), which showed no specific trend.

Of the 470 participants, more than half were women: 52.6% (n=247), 51.9% (244) had higher education level and 73.4% (345) resided in urban area. Regarding education level, the majority of those with higher education level were aged ≥18 to <45 years (150/244=61%) (table 3).

The overall proportion of overweight/obesity with regard to BMI, WC and BF% was 26.4%, 24.9% and 31.1%, respectively, and increased with age (table 2). The highest proportion was observed among participants >45 years. We observed different trends in the prevalence of metabolic parameters and hypertension across age groups. The prevalence of hypertension, high TC, LDL-C and HbA1c increased with age, while that for TGs and HOMA-IR decreased with age. The most prevalent factors were reduced HDL-C (29.4%), hypertension (24.5%) as well as raised LDL-C (21.3%) and HbA1c levels (19.1%). Although hypertension was more prevalent among participants >45 years, only about 9.4% (10) of the participants in this age group were on hypertension medication. Furthermore, high LDL-C and HbA1c were more prevalent among participants >45 years, and low HDL-C was most prevalent among those aged ≥18 to <45 years.

Association between obesity indices and cardiometabolic risk factors

Obesity indices (BMI, WC and BF%) were observed to be associated with one or more risk factors. Participants with high BMI (OR=2.41 (95% CI 1.33 to 4.47)), high WC (OR=3.68 (95% CI 1.81 to 7.52)) or high BF% (OR=2.51 (95% CI 1.40 to 4.51)) were more likely to be hypertensive (table 4). Having high WC (OR=2.52 (95% CI 1.24 to 5.13)) or high BF% (OR=1.91 (95% CI 1.02 to 3.58)) was associated with higher chances of having high LDL-C. Furthermore, BMI (OR=2.08 (95% CI 1.15 to 3.79)) and WC (OR=3.01 (95% CI 1.51 to 6.03)) were associated with HbA1c levels. We further observed increased OR for obesity indices with regard to high TC, high TG, low HDL-C, elevated glucose and HOMA-IR. As the proportion of individuals with high HOMA-IR was very small in our sample (1.28%/n=6), the results were not considered in the final regression analysis. Regarding goodness of fit of the models, values of the Akaike Information Criterion, which estimates the quality of each model relative to that of each of the other models, showed that models including WC as an obesity index tended to have a slightly stronger relationship compared with those including BMI and BF%.

Table 5 presents results of mixed logistic regression models including all three obesity indices to investigate the association with single cardiometabolic risk factors. Compared with the separate regression models, the ORs for most of the associations were attenuated. However, having high WC was again associated with a higher chance of having hypertension (OR=2.62 (95% CI 1.14 to 6.06)) and having high HbA1c levels (OR=2.62 (95%

Table 3 Characteristics of the study population (n=470) by age group (n/%)

	≥5 to <18 years		≥18 to <45 years		45+ years		Total	
	n	%	n	%	n	%	n	%
All	165	100	195	100	110	100	470	100
Gender								
Male	85	51.5	86	44.1	52	47.3	223	47.4
Female	80	48.5	109	55.9	58	52.7	247	52.6
Education level								
Low	122	73.9	45	23.1	59	53.6	226	48.1
High	43	26.1	150	76.9	51	46.4	244	51.9
Area of residence								
Rural	43	26.1	49	25.1	33	30.0	125	26.6
Urban	122	73.9	146	74.9	77	70.0	345	73.4
Obesity indices								
BMI								
Underweight	83	50.3	29	14.9	9	8.18	121	25.7
Normal weight	73	44.2	106	54.4	46	41.8	225	47.9
Overweight/obese	9	5.45	60	30.8	55	50.0	124	26.4
WC								
Normal	165	100	141	72.2	47	42.7	353	75.1
High*	0	0	54	27.7	63	57.3	117	24.9
BF%								
Normal	157	95.2	121	62.1	46	41.8	324	69.0
High†	8	4.86	74	37.9	64	58.2	146	31.1
Hypertension								
Normal	123	74.5	76	39.0	10	9.09	209	44.5
Prehypertension	25	15.8	89	45.6	31	28.2	146	31.1
Hypertension	16	9.70	30	15.4	69	62.7	115	24.5
Hypertension medication‡								
Yes	1	0.61	12	6.38	10	9.43	23	5.02
No	163	99.4	176	93.6	96	90.6	435	95.0
Dyslipidemia§								
TC								
Normal	161	97.6	183	93.8	102	92.7	446	94.9
High	4	2.42	12	6.15	8	7.27	24	5.11
TG								
Normal	157	95.2	186	95.4	105	95.5	448	95.3
High	8	4.85	9	4.62	5	4.55	22	4.68
HDL-C								
Normal	126	76.4	128	65.6	78	70.9	332	70.5
Low	39	23.6	67	34.4	32	29.1	138	29.4
LDL-C								
Normal	141	85.5	163	83.6	66	60.0	370	78.7
High	24	14.5	32	16.4	44	40.0	100	21.3
Diabetes markers¶								
HbA1c								
Normal	142	86.1	166	85.1	72	65.5	380	80.9

Continued

Table 3 Continued

	≥5 to <18 years		≥18 to <45 years		45+ years		Total	
	n	%	n	%	n	%	n	%
High	23	13.9	29	14.9	38	34.5	90	19.1
Plasma glucose								
Normal	136	82.4	167	85.6	88	80.0	391	83.2
High	29	17.6	28	14.4	22	20.0	79	16.8
HOMA-IR								
Normal	162	98.2	193	99.0	109	99.1	464	98.7
High	3	1.82	2	1.03	1	0.91	6	1.28

*High WC was defined as WC ≥90th percentile for children <10 years.[33] Adolescents between 10 and 16 years and adults >16 years WC >94 cm for men and >80 cm for women according to IDF cut-off.[34]
†High BF% for adults (overweight/obese) ≥20 for men and ≥32 for women according to (NIH/WHO) BMI guidelines[36] and ≥85th percentile for children.[35]
‡Missing information from 12 participants (n=458).
§High dyslipidemia for adults; was defined as total serum cholesterol (≥6.2 mmol/L) and LDL-C (≥3.4 mmol/L),[11] low HDL-C <1.03 mmol/L in men or <1.29 mmol/L in women with hypertriglyceridemia (≥1.7 mmol/L)[34] and for children according to IDEFICS study.[39]
¶High diabetes risk markers; high HbA1c (>6.1%),[46] high FPG (≥5.6 mmol/L)[34] and HOMA-IR >4.65 or >3.60 and BMI >27.5 kg/m^2 [43] and for children with high HbA1c (≥97.5th percentile), high FPG ≥95th percentile and HOMA-IR ≥95th percentile.
BF%, body fat per cent; BMI, body mass index; FPG, fasting plasma glucose; HbA1c, glycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

CI 1.12 to 6.15)). Again, as the proportion of individuals with high HOMA-IR levels was very small in our sample (1.28%/n=6), HOMA-IR was not considered in the final regression analysis.

DISCUSSION

This study is the first population-based survey in Unguja Island that investigated the association between multiple obesity indices (BMI, WC and BF%) and multiple cardiometabolic risk factors in a randomly selected Zanzibari population, aged 5–95 years. This study population, as in many other low-income and middle-income countries (LMICs), is undergoing a coexistence of the double burden of underweight children and overweight/obese adults. Generally, about a quarter of the study population were overweight/obese, and obesity increased with age. This observation has also been reported in demographic health surveys from seven sub-Saharan African countries.[48] In the adult population, the prevalence of overweight/obesity was lower than that in Ghana,[7] but higher than in Nigeria[2] and Benin.[49] On the other hand, >50% of the children in this study were underweight, a proportion higher than that in other sub-Saharan African countries (Kenya, Nigeria, South Africa, Equatorial Guinea and Cameroon).[50]

Dyslipidemia is a risk factor for a variety of cardiovascular diseases and is becoming more prevalent in sub-Saharan Africa, particularly the form of low HDL-C.[51 52] Despite the relatively normal levels of TC and TG, low HDL-C affected about 29% of the overall population,

Table 4 Associations between obesity indices (independent) and cardiometabolic risk factors (dependent), adjusted for gender, age, education level, area of residence and hypertension medication (n=470)

Obesity indices	High BMI			High WC			High BF%		
Risk factors	OR	95% CI	AIC	OR	95% CI	AIC	OR	95% CI	AIC
Hypertension	2.41	1.33 to 4.47	504.86	3.68	1.81 to 7.52	499.79	2.51	1.40 to 4.51	503.46
High TC	1.13	0.40 to 3.19	192.74	0.84	0.27 to 2.66	192.71	1.05	0.37 to 2.95	192.79
High TG	1.79	0.55 to 5.77	189.88	2.23	0.58 to 8.66	189.38	1.64	0.52 to 5.14	190.11
Low HDL-C	1.21	0.62 to 2.37	516.08	1.15	0.55 to 2.42	516.25	1.06	0.54 to 2.05	516.37
High LDL-C	1.45	0.78 to 2.69	457.62	2.52	1.24 to 5.13	452.23	1.91	1.02 to 3.58	454.77
High HbA1c	2.08	1.15 to 3.79	442.70	3.01	1.51 to 6.03	438.53	1.75	0.96 to 3.18	445.23
High glucose	2.04	0.93 to 4.50	397.36	2.07	0.84 to 5.07	397.98	1.76	0.80 to 3.87	398.56

AIC, Akaike Information Criterion; BF%, body fat per cent; BMI, body mass index; HbA1c, g lycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

Table 5 Associations between obesity indices (independent) and cardiometabolic risk factors (outcome) adjusted by gender, age, education level and area of residence (n=470)

	Combined obesity indices						
Obesity indices	**BMI**		**WC**		**BF%**		
Risk factors	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**AIC total**
Hypertension	1.19	0.48 to 2.95	2.62	1.14 to 6.06	1.48	0.63 to 3.51	501.39
High TC	1.31	0.25 to 6.79	0.71	0.18 to 2.92	1.01	0.19 to 5.32	196.50
High TG	1.34	0.25 to 7.16	1.90	0.38 to 9.52	1.02	0.19 to 5.52	193.20
Low HDL-C	1.35	0.48 to 3.76	1.09	0.45 to 2.67	0.82	0.98 to 2.25	519.92
High LDL-C	0.63	0.24 to 1.65	2.34	0.99 to 5.50	1.81	0.70 to 4.70	454.68
High HbA1c	1.53	0.61 to 3.81	2.62	1.12 to 6.15	0.82	0.32 to 2.10	441.66
Elevated glucose	1.67	0.55 to 5.06	1.54	0.54 to 4.44	1.03	0.33 to 3.17	400.64

AIC, Akaike Information Criterion; BF%, body fat per cent; BMI, body mass index; HbA1c, g lycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

an indication that low HDL-C affects a large proportion of adults >18 years. The low HDL-C levels observed in our study population might therefore be indicative of a notable and evolving cardiovascular risk in the study region. Our results are in line with a recent study in sub-Saharan Africa and Middle East with 30% of the participants having low HDL-C.[53] Other studies in sub-Saharan Africa reported even higher prevalence of low HDL-C, 43.1% in Nigeria[2] and 80% in Botswana,[54] mostly affecting individuals between 35 and 54 years.

In the present study, a high proportion of participants with high HbA1c (14%) and elevated fasting glucose (18%) are children below 18 years. Since diabetes in children in LMICs has not received much attention, it is likely that there is a high number of children with subclinical complications due to delayed or missed diagnosis as well as a lack of regular monitoring. The high proportions observed in this study are a possible indication that a large proportion of participants with diabetes are not aware of their status and are hence not monitored or treated. The fact that diabetes medication was not reported in this sample supports this assumption. However, when using WHO diabetes diagnostic criteria,[55] that is, HbA1c cut-off ≥6.5% and FPG ≥7.0 mmol/L, the prevalence of diabetes in participants >18 years decreased to 8.14% and 3.05%, respectively (data not shown). The most intriguing result however is the high proportion of children between 5 and <18 years being at high risk for diabetes with elevated FPG levels when using cut-off of ≥5.6 mmol/L. Our results showed that the prevalence of FPG and HOMA-IR in children and adolescents <18 years was in general higher than that of adults >18 years, but less than that of adults >45 years. Results from previous cross-sectional studies have shown that physiological transient insulin resistance develops in children during puberty[56] and decreases again by the end of puberty, regardless of obesity. The decrease in insulin sensitivity in the pubertal period is said to lead to an increase in glucose-stimulated insulin secretion.[57] The high prevalence of FPG and HOMA-IR observed in children and adolescents in our study could hence be due to physiological changes in children and adolescents during prepubertal period and puberty. They could however also be due to misreporting (children did not report having eaten prior to the blood drawing), or to a true high risk within this age group. Considering this, we adjusted for age in the regression models in order to control for possible confounding effects of physiological changes through maturation and ageing. Interestingly, the prevalence of high FPG decreased from approximately 18% to 0.61% when we used the WHO[55] diabetes diagnostic criteria (FPG ≥7 mmol/L) for the same age group (data not shown). This, in our opinion, indicates that the majority of the children are at risk for diabetes, and that the cut-off for HbA1c ≥6.1% as well as elevated FPG ≥5.6 mmol/L seem to be better screening tools for identifying those at risk, earlier.

Our study showed a strong association between BMI, WC and BF% and hypertension in the study population. These findings are in agreement with other studies that also reported an association between hypertension/prehypertension, BMI and WC[58] as well as BF%.[7] Moreover, the association between hypertension and high WC was twice as strong as that with high BMI and high BF%. This result suggests that central obesity may be a better indicator for the risk of hypertension and other cardiovascular diseases in our study population. Thus, optimal body weight control and reduced central obesity risk may have beneficial effects on hypertension control in this population. This study also observed a strong association between WC and LDL-C levels. Obirikorang *et al* also reported similar associations in a comparative cross-sectional study conducted in Ghana.[7]

In the separate models, strong associations were observed between BMI, WC and HbA1c levels, which can be explained by the inter-relation of the two indices, since abdominal fat accumulation increases in proportion to BMI[59] and BMI is one of the main risk factors for diabetes and prediabetes.[60] However, when all three obesity indices were combined, it is only the association between WC and HbA1c levels and hypertension that remained strong. Excessive visceral fat in abdominal obesity is the main source of free fatty acids and inflammatory cytokines, which, according to the literature, might lead to insulin resistance and type 2 diabetes mellitus.[61] This probably explains why WC was strongly associated with diabetes and hypertension in our study population. Therefore, measuring WC using optimal WC cut-off values as was done in this study would be a feasible, less time consuming and cost-effective screening tool to identify at-risk individuals in the Zanzibari population.

This study has some limitations that should be considered. First, this study investigated the association between obesity indices and cardiometabolic risk factors using cross-sectional data; thus, we were not able to examine the impact of changes in obesity indices on risk factors. Second, as is done in many epidemiological studies and clinical trials, we used BIA to estimate BF%. However, compared with skinfold measurements, BIA measurements may underestimate adiposity in children.[62] Third, even though we excluded participants who reported food or beverage intake prior to blood drawing during the data cleaning process, we cannot entirely rule out misreporting of the 'fasting status'. The overall aim of the study was to estimate the prevalence of malnutrition in the Zanzibari population including possible correlates. Therefore, the initial sample size calculation was based on the following considerations: assuming a prevalence of approximately 30% malnutrition in children <5 years of age, a sample size of 323 children <5 years of age was needed to estimate such a prevalence and a corresponding 95% CI with a precision of ±5%.[63] To recruit this number of children, we decided to include entire households. Therefore, 1314 individuals are sufficient to estimate prevalences up to 30% within five absolute percentage points with 95% CI (in children <5 years of age, and their fathers and mothers). The present study consists of a subsample of the study population providing all biomarkers of interest. Even though the decreased sample size may limit the scope of the results obtained—and we acknowledge this as a limitation—we are convinced that the results, presented in the current paper, provide important information for public health stakeholders, policy makers and researchers.

The results of this research can be used for the development of interventions or policies by researchers, stakeholders and government officials. The random selection of the study participants and the standardised assessment of anthropometrical and laboratory measurements are main strengths of the present study. Moreover, we consequently applied age-specific and sex-specific cut-offs that take into account the physiological development characteristic of the young age group, rather than applying the fixed cut-offs used in the adult population. There is little information on the association of multiple obesity indices with multiple cardiometabolic risk factors in this population; hence, our study provides an important contribution towards filling this gap.

CONCLUSION

This study adds to the literature on the association of obesity with higher risks for hypertension, dyslipidemia and type 2 diabetes mellitus, but for the first time in a Zanzibari population. Based on our findings, we recommend that similar epidemiological studies including children, adolescents, adults and elderly set diabetes and/or prediabetes cut-offs of HbA1c at ≥6.1% and/or elevated fasting glucose at ≥5.6 mmol/L. Where feasible, BF% and WC should be used in addition to BMI for screening and monitoring for dyslipidemia and hypertension. We further conclude that there is a need for effective interventions to create awareness as well as for primary prevention strategies for cardiometabolic risks and its complications in Unguja Island, using local multidisciplinary approaches in the local language, Swahili. Additionally, there is a need for health surveillance initiatives that particularly target the age group ≥18 to <45 years. These can also be used to help monitor prevention activities.

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Contributors AH and MAN were responsible for study design. AH, MAN and SK conducted data collection and developed study hypothesis. MAN and CB conducted statistical analyses and KB assisted in the statistical data cleaning. MAN wrote the manuscript and had primary responsibility for final content. MAN, CB, SK, MAS, KLB and AH critically revised the manuscript and gave final consent.

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ORIGINAL ARTICLE

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The association between leptin and inflammatory markers with obesity indices in Zanzibari children, adolescents, and adults

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Abstract

Background: Research from Western populations describes abdominal obesity as a low-grade inflammatory disease; less is known from tropical areas with high pathogen burden.

Objectives: This cross-sectional study investigated whether obesity contributes to low-grade inflammation in 587 individuals from randomly selected households in Zanzibar.

Materials and Methods: The Association between obesity indices (body mass index [BMI], waist circumference [WC], and percentage body fat [%BF]), leptin, and inflammatory markers (C-reactive protein [CRP], interleukin-6 [IL-6] and tumor-necrosis factor-α [TNF-α]) was investigated using multinomial logistic regression analysis, accounting for ordinal outcome variables with four categories; 1st–4th quartile.

Results: Study participants were between 5 and 95 years; 49.6% were male. Mean serum levels were; leptin: 4.3 ± 5.2 ng/ml, CRP: 0.19 ± 0.42 μg/ml, IL-6: 2.8 ± 5 pg/ml, and TNF-α: 5.3 ± 5.2 pg/ml. Obesity indices were associated with leptin and CRP in the third and fourth quartiles in single models. In combined models, associations were observed between BMI (OR = 6.36 [95% CI, 1.09; 34.12]); WC (OR = 4.87 [95% CI, 1.59; 14.94]); and %BF (OR = 19.23 [95% CI, 4.70; 78.66]) and leptin in the fourth quartile; also between %BF and CRP in the third quartile (OR = 3.49 [95% CI 1.31; 9.31]).

Conclusion: Total body fat was associated with low-grade inflammation in this tropical population rather than body fat distribution such as abdominal obesity. This may increase the risk of insulin resistance and other obesity-related metabolic and cardiovascular health endpoints.

KEYWORDS

inflammatory markers, leptin, obesity indices, sub-Sahara Africa

1 | INTRODUCTION

Obesity has been associated with increased risk of developing chronic inflammatory diseases and type 2 diabetes mellitus[1] and is characterized by excessive or abnormal body fat in the adipose tissue. Adipose tissue stores triglycerides and produces adipokines by acting as an endocrine organ,[2] which plays an important role in controlling appetite, lipid metabolism, and insulin resistance.[3] In individuals with obesity, adipocytes are enlarged and their secretory profiles are altered.[4] They produce hormones such as leptin and generate increased amounts of proinflammatory cytokines, which, among others, include interleukin-6 (IL-6) and tumor-necrosis factor (TNF-α).[5] IL-6 and TNF-α stimulate the production of C-reactive protein (CRP) that is generated in the liver.[1] For example, IL-6 is released by the visceral adipose tissue into the portal circulation[3] and is elevated in patients with lipid abnormalities and insulin resistance. Similarly, TNF-α is a proinflammatory cytokine that exerts lipid metabolism and insulin signaling in adipose tissue, thus its levels are elevated in individuals with obesity and reduced with weight loss.[5] CRP has been used as a marker for obesity-related low-grade inflammation, which contributes to insulin resistance.[1] Furthermore, higher levels of inflammatory biomarkers CRP, IL-6, and TNF-α were reported to be associated with increased glycated hemoglobin (HbA1c) as a marker for type 2 diabetes mellitus.[6] In turn, obesity measured using different indices, such as waist circumference (WC) and body mass index (BMI), was associated with higher serum CRP levels and TNF-α.[3,7]

Very few studies in sub-Saharan Africa have investigated the association of leptin and inflammatory markers with obesity indices,[8,9] and none of them explicitly investigated the role of obesity in low-grade inflammation in a Zanzibari population, whose obesity prevalence and the associated comorbidities have increased over the years.[10] The hypothesis of this study is that individuals with obesity are more likely to have elevated leptin levels and inflammatory markers (including CRP, IL-6, TNF-α). To this end, the weight status of Zanzibari children, adolescents, and adults was assessed, depending on their serum levels of leptin, CRP, IL-6, TNF-α, and IL-8. First, the correlation of leptin and inflammatory markers (CRP, IL-6, TNF-α) was analyzed. In a second step, a quasi-linear association of obesity indices with leptin, CRP, IL-6, and TNF-α was investigated.

2 | MATERIALS AND METHODS

2.1 | Study area, study design, and sampling

Zanzibar Island is located approximately 25 km off the coast of Mainland Tanzania. It comprises two main Islands, Unguja and Pemba, and has a population of 1.3 million people, almost 63% of whom live in Unguja.[11] Administratively, Zanzibar is divided into five regions, three in Unguja and two in Pemba. Each region has two districts and each district is subdivided into smaller administrative units, known as Shehias (wards).

Participants for this cross-sectional study were randomly selected in 2013, in a representative population in Unguja Island, with households serving as sampling units.[12] The original study was powered to estimate the prevalence of malnutrition in the Zanzibari population, including possible correlates as described elsewhere.[12] For the present study, a sub-sample of participants fulfilling the study inclusion criteria (age, sex, height, and weight), anthropometric measurements, and provided complete blood samples for leptin and the inflammatory markers (above 5 years) were included. All persons living in the same household were enrolled in the study, irrespective of their age or gender. This was done to help account for inequality aspects. Zanzibari mostly live in extended families, and some families had up to four generations living together in one household, thus providing a large age range. The study was performed according to the Helsinki Declaration and the study protocol was evaluated and approved by the Ethics Committees of the University of Bremen and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee. All participants above 16 years gave a written consent and parents/guardians gave a written consent on behalf of their children who were below 16 years.

2.2 | Socio-economic and demographic indicators

Socio-economic and demographic indicators were assessed at household level.[13] The highest education level of the head of the household was assessed using the International Standard Classification of Education[14] and was categorized as low education level and high education level. The area of residence was recorded and categorized as urban and rural area. As malnutrition is an important factor in this association,[15] the Individual Dietary Diversity Score (IDDS) was calculated based on 14-food groups recommended by the Food and Agriculture Organization,[16] and included as a confounder. Since the median of IDDS in this study was 4, two categories were then developed according to the median; low ≤4 (consumption of less than four food groups) and high >4 (consumption of more than four food groups). All questionnaires were developed in English, translated into Swahili and then back-translated, to check for translation errors.

2.3 | Inclusion and exclusion criteria

In total, 616 participants provided complete blood samples for the analysis of leptin, TNF-α, IL-6, IL-8, and CRP. Participants with serum levels outside the detection limits for leptin and each inflammatory marker were excluded. For the overall study analysis, 587 participants additionally fulfilled the inclusion criteria (availability of data on age, sex, weight, and height) and provided complete covariate information (area of residence, education level, and IDDS). Of these, data from 71 participants were excluded due to pregnancy, non-fasting status, and medication use. All individuals with a high CRP concentration >10 μg/ml ($N = 8$) were excluded as an acute inflammation was presumed. A further $N = 27$ individuals in the highest quartiles of IL-8 as well as CRP were removed from the descriptive analysis as this indicated an acute infection. As extremely high IL-8 levels were observed in many individuals, the variable IL-8 was excluded from the final analysis. Four complete data sets were created: one for leptin and three for each of the inflammatory markers. In order to exclude individuals with a possible acute infection not related to obesity, we excluded 10% of the top extreme values in each data set, thus the final sample sizes included in the final analyses were as follows: CRP = 509; IL-6 = 447; TNF-α = 429; and Leptin = 465.

2.4 | Obesity indices

Bodyweight, body fat percentage (using bioelectrical impedance analysis), height and WC were measured.[12] For children and adolescents, the BMI was calculated as kg/m^2 and then transformed to age- and sex-specific z-score and percentiles, as well as categories for overweight (BMI between >75th and <95th percentile) and obesity (BMI >95th percentile) according to the WHO centile curves.[17,18] For adults, overweight/obesity was defined as BMI ≥25 kg/m^2 as recommended by the WHO.[19] High WC was defined as WC ≥ 90th percentile for children below 10 years[20] and for adolescents below 16 years.[21] For those above 16 years, high WC was defined as WC > 94 cm for males and >80 cm for females, as recommended by the International Diabetes Federation.[21] High percentage body fat (%BF) for participants below 18 years was categorized as ≥85th percentile.[22] For those above 18 years, high %BF was categorized as ≥20 for men and ≥32 for women.[23]

2.5 | Leptin and inflammatory markers

Venous blood was collected from eligible participants in an overnight fasting status. From each participant, 10 ml (6 ml for children) of venous blood was collected in a clot activator vacutainer PET tube (BD, 367896 [10 ml] and BD 368815 [6 ml]) and kept at 4°C until serum was prepared by centrifugation on the same day.[12] Leptin, CRP, IL-6, IL-8, and TNF-α were detected using enzyme-linked immunosorbent assay kits (Human Leptin: K15164C; Human CRP kit: K151EPC; Human cytokines: customized kit (7-spot) from Meso Scale Discovery (Rockville) on a SECTOR Imager 2400A, applying the Discovery Workbench software package (version 4.0). Detection ranges were 10^2–5×10^4 pg/ml (leptin), 2×10^{-2}–2×10 μg/ml (CRP), 2×10^{-1}–6×10^2 pg/ml (IL-6), 1×10^{-1}–5×10^2 pg/ml (IL-8), and 3×10^{-1}–3×10^2 pg/ml (TNF-α).

2.6 | Statistical analysis

Statistical analysis was performed using SAS 9.3 (SAS Institute). Mean and standard deviation for continuous variables were calculated, stratified by weight status. Leptin, CRP, IL6, and TNF-α levels were categorized using sex- and age-group-specific quartile ranges (Q1–Q4). For obesity indices, very severe thinness and severe thinness were merged into one category (severe thinness, Table 2.) and obesity classes I, II, and III were merged into one category (obesity, Table 2). For the analysis of the statistical models (Tables 4 and 5), two categories for each obesity marker that is BMI (overweight/obesity vs. normal weight), WC (high vs. low), and %BF (high vs. low) using sex- and age-specific cut-offs, were created. Pearson's correlation coefficient was calculated to test for intercorrelation. Associations between obesity indices and quartiles of leptin and the inflammatory markers were modeled using multinomial logistic regression analysis. This was based on the LOGISTIC procedure that accounted for ordinal outcome variables with four categories (Q1–Q4), with Q1 serving as the reference variable. Regression analysis was conducted in two steps: (1) 12 models regressing three obesity indices on leptin and each of the three inflammatory markers, (2) Since BMI, WC, and %BF are interrelated, their predictive power on leptin and the three inflammatory markers was investigated in a regression model in which all obesity indices were regressed on each of the outcome variables. Thus four models were regressed for leptin and each of the three inflammatory markers with all the three obesity indices combined in one model. Sex, age range, education level, area of residence, and IDDS categories were included in all multinomial logistic regression analysis models as adjustment variables.

3 | RESULTS

3.1 | Study characteristics

The study participants were between 5 and 95 years old, with the largest proportion of individuals being between ≥5 and <18 years (42%) (Table 1). The mean concentrations for leptin and CRP were higher in participants with overweight/obesity compared to participants who were underweight/normal weight (7.9 ± 5.9 ng/ml vs. 3.5 ± 4.7 ng/ml and 0.33 ± 0.6 μg/ml vs. 0.14 ± 0.4 μg/ml, respectively). On the contrary, the mean concentration values for the inflammatory markers IL-6, IL-8, and TNF-α were slightly higher in underweight/normal weight participants than in those with overweight/obesity. The levels of IL-8 varied over three orders of magnitude in both participant groups, with mean values of 285 ± 311 for underweight/normal participants and 222 ± 301 pg/ml for participants with overweight/obesity. Therefore, IL-8 was excluded from further analysis.

The majority of participants with overweight and obesity were aged 18–45 years (49.1% and 61.5%, respectively) and above

TABLE 1 Descriptive statistics of anthropometric, biochemical variables, and IDDS of the study participants stratified by sex in terms of mean, SD

	Underweight/Normal weight			Overweight/Obesity			All		
	N	Mean ± SD	Range	*N*	Mean ± SD	Range	*N*	Mean ± SD	Range
Age (y)	360	24 ± 16	(4.9, 91)	129	42 ± 17	(8.6, 81)	489	29 ± 18	(4.9, 91)
Height (cm)	360	154 ± 16	(108, 190)	129	160 ± 9.8	(127, 185)	489	155 ± 15	(108, 190)
Weight (kg)	360	46 ± 15	(15, 80)	129	74 ± 13	(29, 116)	489	53 ± 19	(15, 116)
BMI (kg/m^2)	360	19 ± 3.4	(11, 25)	129	29 ± 4.0	(18, 49)	489	21 ± 5.7	(11, 49)
WC (cm)	360	68 ± 12	(12, 96)	129	93 ± 12	(61, 129)	489	74 ± 16	(12, 129)
Body fat (%)	360	17 ± 8.1	(1.6, 53)	129	33 ± 8.4	(9.6, 53)	489	21 ± 11	(1.6, 53)
Leptin (pg/ml)	355	3.5 ± 4.7	(0.05, 21)	85	7.9 ± 5.9	(0.29, 21)	440	4.3 ± 5.2	(0.05, 21)
CRP (μg/ml)	356	0.14 ± 0.4	(0.00, 3.4)	126	0.33 ± 0.6	(0.00, 3.5)	482	0.19 ± 0.4	(0.00, 3.5)
IL-6 (pg/ml)	311	2.9 ± 5.1	(0.09, 29)	109	2.6 ± 4.9	(0.04, 28)	420	2.8 ± 5.0	(0.04, 29)
IL-8 (pg/ml)	293	285 ± 311	(3.2, 1E3)	103	222 ± 301	(2.7, 1E3)	396	269 ± 309	(2.7, 1E3)
TNF-α (pg/ml)	302	5.5 ± 5.3	(1.1, 24)	106	4.7 ± 4.7	(0.99, 24)	408	5.3 ± 5.2	(0.99, 24)
IDDS	360	4.7 ± 1.1	(2.0, 9.0)	129	4.5 ± 1.2	(2.0, 8.0)	489	4.6 ± 1.1	(2.0, 9.0)

Abbreviations: CRP, C-reactive protein; IDDS, individual dietary diversity score; IL-6, interleukin-6; IL-8, interleukin-8; SD, standard deviation; TNF-α, tumor necrosis factor; WC, waist circumference.

45 years (43.6% and 38.5%, respectively). The proportion of participants with Leptin and CRP levels in the fourth quartile was highest among those with obesity (Table 2). Pearson correlation results showed that leptin was positively correlated with CRP ($r = 0.098$, $p = 0.040$) (Table 3).

3.2 | Association between leptin and inflammatory markers and obesity indices

Table 4 presents results of quasi-linear association of single obesity indices with leptin and inflammatory markers, while Table 5 comprises results of obesity indices combined in one model for each outcome. In the separate models, individuals with obesity were more likely to fall in the higher quartiles of leptin and CRP, no association with IL-6 and TNF-α was found (Table 4). In particular, participants who were overweight or obese had a higher chance of having the highest levels of leptin (fourth quartile, model 1a; OR = 73.02 [95% CI, 16.00; 333.2]) and CRP (fourth quartile, model 2a; OR = 5.25 [95 % CI, 2.57; 10.74]). However, these associations were not prominent for CRP quartiles when obesity indices were combined in one model, except for participants with high %BF, who were significantly more likely to have higher CRP levels (third quartile, Table 5, model 6; OR = 3.49 [95% CI, 1.31; 9.31]). Although they were considered simultaneously, obesity indices (BMI and %BF), were significantly associated with high levels of leptin (third and fourth quartiles) and WC only in the fourth quartile (Table 5, model 5).

4 | DISCUSSION

In the present study, the association between obesity indices (BMI, WC, and %BF), leptin and low-grade inflammation (CRP, IL-6, TNF-α) in a Zanzibari population of individuals aged 5 years and above was investigated. Similar to other studies,[12,15,24–26] this study population is undergoing a coexistence of double burden of underweight children and adolescents below 18 years, and overweight/obese adults above 18 years.

The observed association in the individual models between overweight/obesity and leptin is in agreement with previous studies.[7,27,28] Consistent with previous findings in a sub-Saharan African population,[28] increased serum leptin concentrations for high BMI, WC, or %BF were observed, whereas—regardless of weight—leptin levels seem to correlate with all adipose tissue depots.[27] Leptin is a hormone predominantly produced in the white adipose tissue of the human body, and the amount of leptin circulating in the body is proportional to the amount of fat of an individual.[29] Thus, the key factor influencing leptin concentrations in human is adipose tissue mass.

Similar to other studies,[30–32] this study population reported a significant association between overweight/obesity and elevated CRP levels. However, the possibility of obesity-related comorbidities such as hypertension, diabetes, and probably high infection contributing to elevated CRP levels, could not be excluded. This study population included healthy (nonhospitalized) participants; hence the elevated CRP levels are more likely to be linked to adiposity. High %BF in the combined models of the present study was significantly linked to high CRP levels in the third quartile. The lack of significance

TABLE 2 Characteristics of the study population (N = 359)

	Severe thinness		Thinness		Normal weight		Overweight		Obese		All	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
All	52	100	62	100	177	100	55	100	13	100	359	100
Socio-demographic information												
Gender												
Male	30	57.7	32	51.6	79	44.6	30	54.5	7	53.8	178	49.6
Female	22	42.3	30	48.4	98	55.4	25	45.5	6	46.2	181	50.4
Age range												
5–18	37	71.2	43	69.4	66	37.3	4	7.27	0	0.00	150	41.8
18–45	10	19.2	14	22.6	73	41.2	27	49.1	8	61.5	132	36.8
45+	5	9.62	5	8.06	38	21.5	24	43.6	5	38.5	77	21.4
Educational level												
Low	43	82.7	36	58.1	80	45.2	24	43.6	5	38.5	188	52.4
High	9	17.3	26	41.9	97	54.8	31	56.4	8	61.5	171	47.6
Area of residence												
Rural	15	28.8	19	30.6	52	29.4	12	21.8	5	38.5	103	28.7
Urban	37	71.2	43	69.4	125	70.6	43	78.2	8	61.5	256	71.3
Leptin and inflammatory markers in quartiles												
Leptin												
First quartile	28	53.8	17	27.4	50	28.2	2	3.64	0.00	0.00	97	27.0
Second quartile	12	23.1	26	41.9	40	22.6	11	20.0	1	7.69	90	25.1
Third quartile	7	13.5	12	19.4	47	26.6	18	32.7	5	38.5	89	24.8
Fourth quartile	5	9.62	7	11.3	40	22.6	24	43.6	7	53.8	83	23.1
CRP												
First quartile	18	34.6	21	33.9	50	28.2	12	21.8	1	7.69	102	28.4
Second quartile	13	25.0	14	22.6	49	27.7	14	25.5	3	23.1	93	25.9
Third quartile	12	23.1	17	27.4	50	28.2	17	30.9	3	23.1	99	27.6
Fourth quartile	9	17.3	10	16.1	28	15.8	12	21.8	6	46.2	65	18.1

(Continues)

TABLE 2 (Continued)

	Severe thinness		Thinness		Normal weight		Overweight		Obese		All	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
IL-6												
First quartile	11	21.2	14	22.6	54	30.5	23	41.8	2	15.4	104	29.0
Second quartile	15	28.8	15	24.2	49	27.7	13	23.6	3	23.1	95	26.5
Third quartile	18	34.6	18	29.0	41	23.2	12	21.8	7	53.8	96	26.7
Fourth quartile	8	15.4	15	24.2	33	18.6	7	12.7	1	7.69	64	17.8
TNF-α												
First quartile	6	11.5	22	35.5	52	29.4	13	23.6	2	15.4	95	26.5
Second quartile	17	32.7	10	16.1	45	25.4	19	34.5	5	38.5	96	26.7
Third quartile	18	34.6	14	22.6	40	22.6	16	29.1	3	23.1	91	25.3
Fourth quartile	11	21.2	16	25.8	40	22.6	7	12.7	3	23.1	77	21.4
IDDS												
IDDS category												
Low	20	38.5	30	48.4	73	41.2	22	40.0	7	53.8	152	42.3
High	32	61.5	32	51.6	104	58.8	33	60.0	6	46.2	207	57.7

Abbreviations: CRP, C-reactive protein; IDDS, individual dietary diversity score; IL-6, interleukin-6; TNF-α, tumor necrosis factor.

TABLE 3 Correlation between leptin and inflammatory markers

Leptin and inflammatory markers	Pearson correlation coefficients Prob > |r| under H0: Rho = 0 Number of observations CRP	IL-6	TNF-α	Leptin
CRP	1.00	−0.065	−0.065	**0.099**
		0.19	0.19	**0.04**
	482	414	404	**434**
IL-6		1.00	**0.764**	−0.022
			<0.0001	0.67
		420	**400**	381
TNF-α			1.00	−0.01717
				0.7424
			408	369
Leptin				1.00
				440

Note: The bold values indicate statistically significant (p-value < 0.05).
Abbreviations: CRP, C-reactive protein; IL-6, interleukin-6; TNF-α, tumor necrosis factor.

in the highest quartile of %BF might have been due to the small sample size of participants in this particular quartile. Nevertheless, %BF proved to be the strongest correlate of CRP in this study population, affirming that high body fat plays an important part in stimulating increased levels of circulating CRP.[33] Similar results were reported by Forouhi et al., who investigated the association between CRP and %BF in Europeans and South Asians. In the study, %BF and BMI showed a significant association with CRP in Europeans, while visceral fat and waist girth were strongly associated with CRP levels in South Asians.[34]

Furthermore, a US study reported significant associations between CRP and BMI of young adults,[31] while studies from Tunisia[35] and from Teheran[3] reported associations between high WC and CRP. In this study, high %BF was observed to be the strongest correlate for CRP, compared to high BMI and high WC. This is probably due to the higher proportion of younger (5–18 years) underweight participants in the Zanzibari data set compared to the older populations in the Tunisian (35–70 years)[35] and the US third NHANES wave (17–39 years)[31] studies referred to above. Furthermore, the fact that the proportion of severe thinness and thinness participants for the CRP levels in the fourth quartile in our study was higher than that in the normal weight group, leads to the assumption that the higher CRP levels in the underweight participants were due to other causes such as a weak immune system/infection. This would then have attenuated the association between BMI/WC and CRP in the overall sample. Nevertheless, our findings show that %BF may serve as an indicator for obesity-related increase of CRP release and insulin resistance in the study population. In summary, the findings from the previous studies[3,31,34,35] and the observations reported in the current study confirm strong association between obesity indices and CRP.

Overall, a positive correlation was observed between serum concentration of leptin and CRP independent of the obesity indices, as reported previously.[36] This can easily be explained by the proinflammatory effect of leptin, which induces the release of CRP by hepatocytes.[37] In turn, CRP leads to leptin resistance by interacting with the leptin receptor at a site distinct from the leptin binding site.[38] Besides leptin, IL-6 is secreted by adipocytes and stimulates the synthesis of CRP and other acute-phase proteins.[36] Therefore, the levels of several cytokines in the study population were also explored.

Previous studies have reported associations between obesity and high IL-8 concentrations[39] secreted by adipocytes.[40] For this reason, IL-8 was also considered an outcome of interest in our study population. However, extremely high IL-8 values were observed (up to more than 1000 pg/ml, mean 269 ± 309 pg/ml), leading to the exclusion of the participants concerned from the final regression models. This was done to avoid misinterpretation due to bacterial and/or viral infections, which might have affected the expression level of other inflammatory markers.

The overall mean IL-6 concentration in the present study (2.9 pg/ml) was slightly higher than that of males (2.5 pg/ml) and females (2.3 pg/ml) reported in a West African (Ghana and Nigeria) study population,[32] but lower than the cut-off of 5 pg/ml, which was considered as high IL-6 concentration in a Tanzanian study.[41] The fact that the West African population was more urbanized than the current population, and thus strongly associated to low-grade inflammation, might explain the difference in findings. The current population was masked by high inflammation rate, thus no association was found with IL-6. However, IL-6 showed no significant association with any of the obesity markers in the present study, which is contradictory to other studies.[3,7] Like leptin, IL-6 and TNF-α are

TABLE 4 Association between each obesity index with leptin and inflammatory markers with each obesity index, adjusted for age group, sex, education level of the head of household, and area of residence and IDDS (models 1–4; a–c)

Dependent variable: Leptin and inflammatory markers			Weight status (BMI) (overweight/obesity vs. normal weight) OR (95%)	Waist circumference (high vs. normal) OR (95%)	Body fat % (high vs. normal) OR (95%)
Models	***N***	**Quartiles**	**(a)**	**(b)**	**(c)**
1. Leptin (*N* = 440)	113	First quartile	Ref	Ref	Ref
	112	Second quartile	**7.73 (1.64; 36.45)**	1.90 (0.67; 5.17)	**5.80 (1.79; 18.75)**
	114	Third quartile	**28.61 (6.38; 128.3)**	**7.73 (2.97; 20.11)**	**22.01 (6.97; 69.50)**
	101	Fourth quartile	**73.02 (16.00; 333.2)**	**21.55(7.99; 58.09)**	**87.19 (25.80; 294.7)**
2. CRP (*N* = 482)	130	First quartile	Ref	Ref	Ref
	126	Second quartile	**2.31 (1.18; 4.55)**	1.92 (0.95; 3.89)	**2.27 (1.18; 6.44)**
	129	Third quartile	**2.42 (1.23; 4.78)**	**2.30 (1.14; 4.62)**	**3.41 (1.77; 6.55)**
	97	Fourth quartile	**5.25 (2.57; 10.74)**	**4.03 (1.93; 8.45)**	**4.97 (2.46; 10.05)**
3. IL-6 (*N* = 420)	114	First quartile	Ref	Ref	Ref
	105	Second quartile	0.72 (0.37; 1.41)	1.24 (0.60; 2.53)	0.95 (0.49; 1.83)
	107	Third quartile	0.82 (0.43; 1.59)	1.38 (0.68; 2.81)	1.17 (0.61; 2.25)
	94	Fourth quartile	0.67 (0.34; 1.34)	0.96 (0.45; 2.04)	0.84 (0.42; 1.67)
4. TNF-α (*N* = 408)	108	First quartile	Ref	Ref	Ref
	105	Second quartile	1.59 (0.81; 3.12)	1.19 (0.58; 2.47)	1.11 (0.57; 2.15)
	99	Third quartile	1.26 (0.63; 2.53)	0.88 (0.42; 1.84)	0.92 (0.46; 1.82)
	96	Fourth quartile	0.92 (0.45; 1.87)	1.01 (0.48; 2.13)	0.86 (0.43; 1.71)

Note: The bold values indicate statistically significant (p-value < 0.05).
Abbreviations: BMI, body mass index; CRP, C-reactive protein; IDDS, individual dietary diversity score; IL-6, interleukin-6; TNF-α, tumor necrosis factor.

produced and released from human adipocytes, and their elevated levels have been found to be strongly associated with all measures of obesity in other studies from Europe or the United States.[42,43]

Our unexpected results regarding the higher mean concentration of IL-6 and TNF-α in underweight/normal weight participants and the fact that no significant association was observed in overweight/obese participants may be due to underlying causes (infection-weak immune system) or malnutrition,[44] which were not investigated in this study. It is important to note that in the Zanzibari population, such an effect is possibly obscured by an increased secretion of IL-6 and TNF-α from other sources as regulators of the immune system. Thus, likely to be more challenged in this population compared to populations in high income countries.

The major strength of this study is that it represents the first population-based study in Zanzibar, Tanzania, enrolling nonhospitalized individuals to investigate the association of three different obesity-related indices with leptin and different inflammatory markers in a sample including children from 5 years, adolescents, younger, middle age, and older adults.

The random selection of the study participants, the use of standardized anthropometrical and laboratory measurements, and the exclusion of participants with extreme values of leptin and inflammatory markers/indications of infection enhanced the quality of the data used and the statistical analyses. The overall sample size in this study was similar to other studies,[3] but advantageously involved a wide range of age groups, although limiting the availability of data in single age groups, particularly in the group above 45 years ($N = 77$, 21.4 %). The overall study was powered to investigate the prevalence of malnutrition in the Zanzibari population and resulted in a higher sample size compared to the current sample size used for this analysis. While we acknowledge that the decreased sample size of the current analysis is a limitation that may lessen the scope of the results obtained, we are convinced that our results contribute to the literature of sub-Saharan African studies and provide insight into associations in developing economies with tropical climates. This study is further limited by the cross-sectional design, which may not accurately reflect longitudinal associations between changes in body fat and the long-term inflammation status of the study population.

5 | CONCLUSION

Adipocytes dysfunction—due to adipose expansion—may have local or systemic effects on inflammatory responses, which may then contribute to the initiation and progression of obesity-induced metabolic and cardiovascular risk factors, such as type 2 diabetes

TABLE 5 Multivariate association between three obesity indices with leptin and inflammatory markers with all three obesity indices combined, adjusted by age group, sex, education level of the head of household, area of residence models, and IDDS (models 5–8)

Dependent variable: Leptin and inflammatory markers Models	*N*	Quartiles	Weight status (BMI) (overweight/obesity vs. normal weight) OR (95%) (a)	Waist circumference (high vs. normal) OR (95%) (b)	Body fat % (high vs. normal) OR (95%) (c)
5. Leptin (*N* = 440)	113	First quartile	Ref	Ref	Ref
	112	Second quartile	3.34 (0.54; 20.60)	1.01 (0.33; 3.07)	3.14 (0.78; 12.71)
	114	Third quartile	**5.75 (1.00; 33.03)**	2.64 (0.90; 7.70)	**6.24 (1.60; 24.26)**
	101	Fourth quartile	**6.36 (1.09; 37.12)**	**4.87 (1.59; 14.94)**	**19.23 (4.70; 78.66)**
6. CRP (*N* = 482)	130	First quartile	Ref	Ref	Ref
	126	Second quartile	1.49 (0.52; 4.27)	1.20 (0.52; 2.78)	1.56 (0.56; 4.29)
	129	Third quartile	0.83 (0.29; 2.32)	1.25 (0.54; 2.88)	**3.49 (1.31; 9.31)**
	97	Fourth quartile	2.33 (0.76; 7.18)	1.72 (0.71; 4.17)	2.02 (0.67; 6.13)
7. IL-6 (*N* = 420)	114	First quartile	Ref	Ref	Ref
	105	Second quartile	0.43 (0.14; 1.32)	1.58 (0.67; 3.74)	1.46 (0.48; 4.45)
	107	Third quartile	0.40 (0.14; 1.19)	1.58 (0.67; 3.73)	1.89 (0.64; 5.6)
	94	Fourth quartile	0.50 (0.16; 1.51)	1.20 (0.49; 2.98)	1.34 (0.44; 4.13)
8. TNF-α (*N* = 408)	108	First quartile	Ref	Ref	Ref
	105	Second quartile	2.56 (0.85; 7.68)	1.02 (0.42; 2.47)	0.54 (0.18; 1.62)
	99	Third quartile	2.22 (0.71; 6.95)	0.80 (0.32; 1.96)	0.57 (0.18; 1.77)
	96	Fourth quartile	1.02 (0.34; 3.03)	1.16 (0.47; 2.88)	0.79 (0.27; 2.28)

Note: The bold values indicate statistically significant (p-value < 0.05).

Abbreviations: BMI, body mass index; CRP, C-reactive protein; IDDS, individual dietary diversity score; IL-6, interleukin-6; TNF-α, tumor necrosis factor.

mellitus. High %BF in this population was associated with higher leptin and higher CRP concentrations, which have been closely linked to insulin resistance, a known risk factor for noncommunicable diseases. The results of this study add important information for the development of obesity prevention interventions promoting healthy diets and healthy lifestyles that will consequently help to reduce cardiovascular risk in this study population.

This study contributes to the general understanding on the association between obesity—measured as fat mass—, leptin and low-grade inflammation in the sub-Saharan African population. Additionally, the results provide important information for public health stakeholders, policy makers, and researchers in similar contexts.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

This manuscript represents original work that has not been published previously and is currently not considered by another journal. The authors' responsibilities were as follows: Antje Hebestreit and Maria Adam Nyangasa developed the idea for this manuscript and analysis strategy. Maria Adam Nyangasa and Christoph Buck conducted statistical analyses interpreted the data; Maria Adam Nyangasa wrote the manuscript and had primary responsibility for final content and submitting the manuscript for publication; Maria Adam Nyangasa, Antje Hebestreit, Christoph Buck, and Soerge Kelm revised the manuscript critically for important intellectual content; Maria Adam Nyangasa, Christoph Buck, Soerge Kelm, Mohammed Ali Sheikh, Kathrin Günther, and Antje Hebestreit were responsible for revisions and final approval of the manuscript.

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Anthropometric and Biochemical Predictors for Hypertension in a Cross-Sectional Study in Zanzibar, Tanzania

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Background: Aim of this study was to describe the proportion of hypertension among Zanzibari of different age-groups and to detect possible correlates of this non-communicable disease.

Methods: In 2013 a cross-sectional survey was conducted in Unguja Island, Zanzibar. A total of 235 randomly selected households, including 1,229 (2 to 95 years) eligible study participants, were examined. Association between objectively assessed obesity markers, salt intake and hypertension were investigated. Estimates of 24 h sodium and potassium excretion from a single morning spot urine specimen were calculated and used as surrogate for salt intake. The association between overweight/obesity and hypertension in different age-groups was assessed in multilevel logistic regression models. Further associations between salt intake and hypertension were analyzed.

Results: Measures of systolic and diastolic blood pressure as well as proportion of overweight/obesity and hypertension both increased with age. Overweight and obesity were significantly associated with hypertension in adults. Moreover, thinness seems to be associated with hypertension as well. We observed a significantly reduced chance of hypertension for higher urinary sodium-to-potassium compared to a lower ratio in children.

Conclusion: Overweight/obesity and hypertension were highly prevalent (>47% of adults >40 years are overweight or obese and >69% are hypertensive in the same age group) in our sample. Weight status was confirmed as a correlate of high blood pressure in our sample from Zanzibar, Tanzania. To early and effectively prevent related severe cardiovascular outcomes, screening strategies but also monitoring strategies are required for this population.

Keywords: blood pressure, body fat, body mass index, hypertension, salt, sub-Sahara Africa, waist circumference

INTRODUCTION

Hypertension is one of the leading causes of death worldwide (1, 2). But in contrast to other cardiovascular risk factors, the risk for hypertension is modifiable (3). While prevalence of hypertension in developed countries stabilizes around 35% or decreases, the prevalence rises in African countries. An increase of 89% from 2000 to 2025 is expected (4). By 2025 almost 75% of hypertensive patients will be found in developing countries (5). Today more than one third of the African adult population is hypertensive (2). And with 46% prevalence of hypertension in adults older than 25 years, Africa has the highest age-standardized hypertension prevalence worldwide (6). Due to few symptoms, hypertension is poorly detected and, even when detected, often untreated and barely controlled (6–8). Although the risk for hypertension increases with age, in sub-Sahara Africa, even young adults suffer from it (9, 10). Higher prevalence is found in lower socio-economic groups and follows demographic gradients from rural to urban areas (2, 3, 11). Overweight and obesity have been found to be modifiable risk factors for hypertension (12). Furthermore, salt intake is known as another important risk factor for development of hypertension. In African countries high concentrations of salt for food preparation and preservation has been established for a long time, due to poor possibilities of refrigeration or availability of gustatory ingredients (2).

Tanzania is one of Africa's low-income countries. Globalization as well as sedentary lifestyle has noticeable effects on health of the Tanzanian population (11). Like other developing countries, underweight and overweight/obesity and related comorbidities are present in the same population. This results in a rapidly increasing number of non-communicable diseases, such as hypertension and respective risk factors (13). Since obesity and salt intake are two reversible causes for high blood pressure (3, 14), we aimed to investigate associations between objectively measured anthropometric and biochemical markers such as urinary sodium and potassium excretion from morning spot urine and blood pressure in different age-groups in a study population from Zanzibar, Tanzania.

MATERIALS AND METHODS

Study Design and Participants

Data collection was conducted in a cross-sectional survey in 2013. Study participants were identified in 244 randomly selected households in Zanzibar, Tanzania. Power calculations, recruiting strategies and general measurement methods were described elsewhere (15). Briefly, the survey was carried out in 80 small administrative Wards (Shehias) in Unguja, one of the two main islands of Zanzibar. Survey sample and study sample are described in **Figure 1**. Overall, 1,541 individuals were contacted and 98 of them refused to participate. Of the 1,443 participants, 214 were excluded for this study due to missing information on age, weight, height and blood pressure measurements.

Data Collection

Socio-demographic information on sex, age, and education level was collected through an interview-based questionnaire, which was completed for all participants above an age of 2 years. Information on young children were reported by their parents. Questionnaires were developed in English, translated into Swahili, and then back-translated to control for translation errors. All forms and questionnaires were administered and well-explained in Swahili by trained fieldworkers. Educational level of study participants was assessed using the International Standard Classification of Education (ISCED) (16). Based on this classification, we distinguished between low education (no or pre-primary education), primary education (primary school) and secondary education (secondary school and above).

Anthropometric measurements and collection of morning spot urine were carried out in fasting status following standardized procedures (17–19).

All anthropometric measurements and collection of biosamples were carried out considering standard operating procedures and study protocols. The measurement of proportion of body fat (% BF) and body weight was carried out barefoot using an electronic scale (TANITA BC-420 SMA, Germany) to the nearest 0.1 kg. Height of participants was measured to the nearest 0.1 cm using a stadiometer (Seca 213 stadiometer, UK) or a measuring board (Seca 417 measuring board, UK) for young children <2 years.

Body Mass Index (BMI) was calculated by dividing weight in kilograms by height squared in meters (kg/m^2). For adults, overweight was defined as BMI $\geq$25 kg/m^2; obesity was defined as BMI $\geq$30 kg/m^2 according to the WHO (20). For children and adolescents up to an age of 19, BMI was transformed to age-and sex-specific z-score and percentiles using the WHO SAS macros "Anthro"[1] and "AnthroPlus"[2] in SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA). Categories for overweight (BMI between >75th and <95th percentile) and obesity (BMI > 95th percentile) were assigned according to the WHO centile curves (21). Waist circumference (WC) was measured at the midway point between the lower rib margin and the iliac crest in standing position and while wearing light clothing using an inelastic measuring tape (SECA 201) to the nearest 0.1 cm (22). % BF and WC were categorized into quartiles.

A digital automatic blood pressure monitor (Omron T3) was used to measure the systolic and diastolic blood pressure according to a standardized procedure (15). According to this, participants were asked to rest for at least 15 min before measurement. Measurements were taken on the naked right upper arm in sitting position with legs uncrossed. The middle of the blood pressure cuff has to be on heart level. Cuff length was determined according to the arm circumference, which was measured to the nearest 0.1 cm using an inelastic measuring tape (SECA 201). Two measurements were taken at

Abbreviations: ISCED, International Standard Classification of Education; % BF, proportion of body fat; BMI, Body Mass Index; NIH, National Institutes of Health; WHO, World Health Organization; WC, waist circumference; SUTAS, Sustainable Use of Tropical Aquatic Systems.

[1]https://www.who.int/childgrowth/software/en/
[2]https://www.who.int/growthref/tools/en/

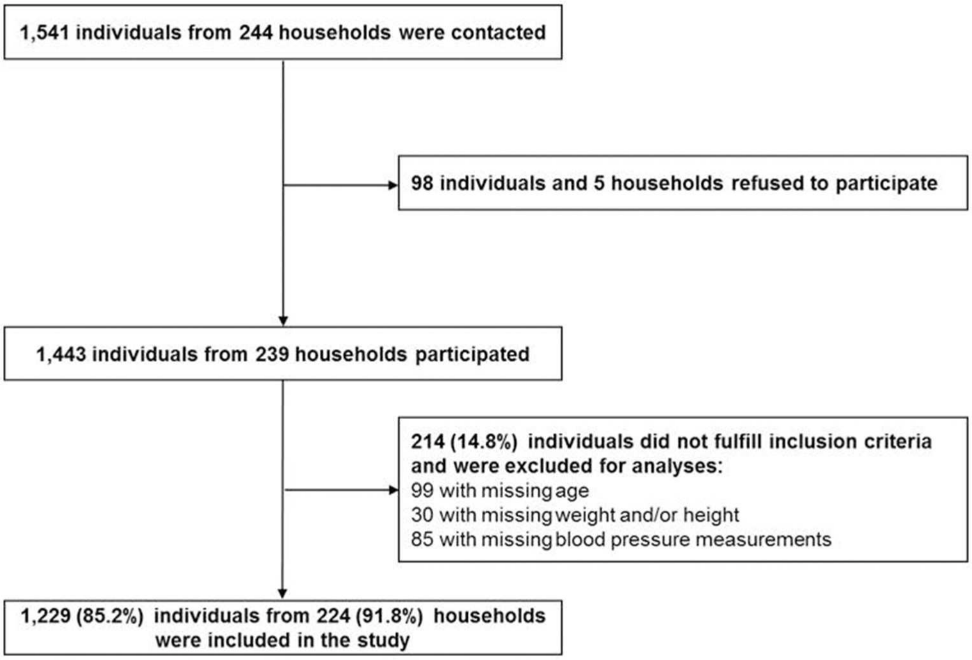

FIGURE 1 | Flow diagram of participants from recruitment to analysis.

an interval of 5 min plus a third measurement in case of >5% difference in blood pressure between the previous two readings. Mean of the two measurements with the smallest difference was taken into analyses. In case of similar differences between the three measurements, mean of all three measurements was taken. Classification was conducted with respect to participants' age. For children, blood pressure between the 90th and 95th percentile were classified as pre-hypertensive. Children with a blood pressure above the 95th percentile were classified as hypertensive (23). Adolescents and adults over 14 years with systolic blood pressure of ≥130 mmHg or diastolic blood pressure ≥80 mmHg were classified pre-hypertensive. Persons were classified as hypertensive, either if their systolic blood pressure was greater or equal 140 mmHg, their diastolic blood pressure reached a value of ≥90 mmHg (24) or regular use of anti-hypertensive medication was reported. As pre-hypertensive native African children have a high risk for developing hypertension in later life (25), pre-hypertensive as well as hypertensive children (2–≤19 years) were classified as hypertensive for statistical analysis.

Urinary excretion of sodium, potassium and creatinine was measured in a 25 ml fasting status morning spot urine sample by ion-selective electrodes (ErbaLyteCaPlus) or picric acid assay (R&D creatinine kit). Twenty four hour urinary excretion of sodium and potassium was calculated from this single measurement using the Kawasaki formula (26). For using the Kawasaki formula, 24 h creatinine excretion was estimated according to another formula by Kawasaki et al. (27) accounting for age, sex, weight and height. Estimated excretion of sodium and potassium was used as surrogates for sodium and potassium intake.

Statistical Analysis

Descriptive analyses were conducted to calculate sample characteristics regarding systolic and diastolic blood pressure, weight status and urinary excretion of sodium, potassium and creatinine as well as educational level and area of residence stratified by age-groups [young children (2–≤9 years), children (>9–≤ 19 years), young adults (>19–≤ 40 years), adults (>40 years)] and sex. Statistics were provided in mean and standard deviation (SD) for continuous variables, and frequency (N) and proportions (%) for categorical variables.

Multilevel logistic regression was applied to calculate odds ratios (OR) and 95% confidence intervals (CI) in order to identify associations between anthropometric and biochemical markers with hypertension dichotomized as hypertensive and pre-hypertensive vs. normal blood pressure. Potential clustering within Shehias was considered in terms of a random intercept. With regard to a complete case analysis, item missing in variables included in the study, lead to differing sample size in each regression model. Quartiles of %BF and WC as well as BMI and 24 h sodium-to-potassium ratio were included as independent variables into each regression model. All models were adjusted for age, sex and area of residence and stratified by age-groups. Since education is highly correlated with age in children, adjustment for educational level for all participants ≤ 19 years was done using the highest educational level in their household. For adults, personal information on educational level was used.

We further adjusted for height in adults >19 years and height for age z-scores in children ≤ 19 years (23). Goodness of fit for all models was determined via the BIC. Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, North Carolina, USA) and particularly mixed logistic regression models were conducted using the GLIMMIX procedure.

RESULTS

Study Characteristics

In this study, a total of 1,229 participants, aged 2–95 years, fulfilled the inclusion criteria. Inclusion of study participants was described in **Figure 1**. The study sample consisted of 622 children and adolescents aged 2–≤ 19 years with about 49% females and 607 adults aged 19+ years with 60% females (**Table 1**).

Mean age for children and adolescents was 11 years and for adults 40 years in both sexes. Proportion of individuals from urban and rural residence was comparable in the sample with an exception in female children (>9–≤ 19 years) and male young adults (>19–≤ 40 y.), where about 60% of participants lived in urban areas.

Concerning participants' weight status, the highest percentage of participants per group changed from severe thinness in young children (2–≤ 9 years) over thinness in children and adolescents (>9–≤ 19 years) to normal weight or overweight in adults (>19 years). Systolic and diastolic blood pressure (**Table 1**, **Supplementary Table 1**) and the prevalence of hypertension and overweight/obesity increased with age (**Figure 2**, **Supplementary Table 1**).

Associations Between Anthropometric and Biochemical Markers and Hypertension

Results of the mixed logistic regression models are shown in **Figure 3** and **Table 2**. Young adults aged >19–≤ 40 years, were more likely to be hypertensive or pre-hypertensive if they were overweight [OR = 3.0 (95% CI 1.3, 6.8)], but not obese compared to normal weight participants in the respective age-group. In adults >40 years, only obese [OR = 3.9 (95% CI 1.3, 11.1)] but not overweight participants were found to be more likely hypertensive compared to normal weight participants.

When comparing the fourth to the first quartile of %BF, we also observed a significantly higher chance for hypertension in adults >40 years [OR = 3.4 (95% CI 1.1, 10.8)]. Furthermore, an increasing chance for hypertension was observed with increasing BMI as well as with increasing quartiles of %BF and WC in all age-groups, even though not significant.

We further observed a significant association between 24 h sodium-to-potassium ratio as marker for salt intake and hypertension in children aged >9–≤ 19 years [OR = 0.7 (95% CI 0.6, 0.9), for all models (%BF, WC, BMI)]. Moreover, the direction of association between salt intake and hypertension changes with age. Children with higher salt intake, determined by urinary sodium-to-potassium ratio, were less likely to be hypertensive, whereas higher intake in adults over the age of 40 years was associated with hypertension. In adults, aged 19 to 40 years, salt intake showed no association with hypertension. Variance of random effects in mixed models varied from 0.9 in adults to 1.5 in young children, indicating a considerable amount of unexplained variance on the Shehia level (see **Table 2**).

DISCUSSION

This study was part of the SUTAS (Sustainable Use of Tropical Aquatic Systems) survey and was conducted in order to identify anthropometric and biochemical associations with hypertension and pre-hypertension in Unguja Island, Zanzibar, Tanzania. This was the first epidemiological study in Unguja Island, Zanzibar, investigating associations between markers of overweight/obesity and salt intake and hypertension using standardized methods in a randomized sample of members of a household. The most recent surveillance report from the Zanzibar observed systolic and diastolic blood pressure rates and hypertension proportions that were for men and women (age-groups 25–44 years and 45–64 years) lower compared to the respective age-groups of the present study (28). Recently, there have been studies on hypertension in Tanzania (7, 29, 30), but most of them focus on the adult population of the mainland (7, 30). To our knowledge this is the first study providing information on associations between anthropometric and biochemical markers and hypertension not only in adult populations but also for Zanzibari children from an age of 2 years onwards.

In our sample, prevalence of hypertension increased with age, and thus supports the findings of other studies in Tanzania (7, 29). Overall, about 16% of children (2–≤ 19 years) in the study population suffered from hypertension. A recent meta-analysis on prevalence of elevated blood pressure in children and adolescents in Africa reported on a prevalence range from 0.2 to 24.8% (31). Pooling all studies, they found a pooled prevalence of 5.5% for blood pressure >95th percentile. However, pooled prevalence in Eastern Africa was found to be higher (9.0%). In addition, our results are comparable to the reported hypertension prevalence (8.4% up to 24.4%) in a South African study investigating children between 5 and 18 years (25). Additionally, 14% of children (2–≤ 19 years) in our study sample were pre-hypertensive, which corresponds to findings from the respective South African sample and the recent meta-analysis (25, 31). In adults (>19 years), prevalence of hypertension was 47% and considering also the prevalence of pre-hypertension (15%), the hypertension prevalence in our sample was higher compared to the hypertension prevalence in the whole of Tanzania (39%), reported by WHO in 2011 (32). However, considering only the age group of adults (>40 years) we found a hypertension prevalence of about 70%, which is similar to the results of a comparable study in adults older than 50 years in South Africa (33).

BF% and WC are good indicators for children's weight status (34), but hypertension in children is not only determined by weight but also by height (23). Considering BF%, WC and BMI as different markers for weight status, logistic regression models including BMI showed the best goodness of fit in young children (2–≤ 9 years). This indicates that BMI, including not only weight but also height, seems to be a better predictor for hypertension than other markers of weight status in young children. Participants with higher BMI seemed to be more likely to be hypertensive in all age-groups. A lower BMI was

TABLE 1 | Characteristics of the study population stratified by age and sex.

	Young children (2–≤ 9 y.) (*N* = 261; 21.2%)				Children (>9–≤ 19 y.) (*N* = 361; 29.4%)				Young adults (>19–40 y.) (*N* = 327; 26.6%)				Adults (>40 years) (*N* = 280; 22.8%)			
	Male (*N* = 134; 51.3%)		Female (*N* = 127; 48.7%)		Male (*N* = 186; 51.5%)		Female (*N* = 175; 48.5%)		Male (*N* = 128; 39.1%)		Female (*N* = 199; 60.9%)		Male (*N* = 116; 41.4%)		Female (*N* = 164; 58.6%)	
Age [Mean (SD)]	6.1	(1.9)	5.8	(1.9)	13.9	(2.8)	14.0	(2.7)	26.3	(6.3)	28.8	(6.6)	55.7	(10.1)	53.3	(9.8)
Blood pressure [Mean (SD)]																
SBP (in mm/Hg)	103.2	(10.9)	103.6	(12.6)	116.8	(13.5)	116.1	(11.8)	128.1	(13.5)	125.5	(17.0)	155.1	(27.2)	153.9	(32.4)
DBP (in mm/Hg)	66.6	(9.1)	67.6	(10.1)	70.5	(8.9)	72.9	(8.3)	78.1	(8.5)	79.5	(11.2)	90.8	(14.0)	89.6	(14.8)
Hypertension [*N* (%)]*																
Yes	23	(17.2)	25	(19.7)	20	(10.8)	30	(17.1)	36	(28.1)	52	(26.1)	82	(70.7)	113	(68.9)
Prehypertension	21	(15.7)	15	(11.8)	31	(16.7)	20	(11.4)	25	(19.5)	35	(17.6)	16	(13.8)	14	(8.5)
Weight status[†]																
Severe thinness	71	(53.0)	52	(40.9)	42	(22.6)	25	(14.3)	7	(5.5)	14	(7.0)	2	(1.7)	5	(3.0)
Thinness	33	(24.6)	48	(37.8)	59	(31.7)	37	(21.1)	14	(10.9)	15	(7.5)	8	(6.9)	9	(5.5)
Normal weight	30	(22.4)	25	(19.7)	76	(40.9)	89	(50.9)	82	(64.1)	103	(51.8)	51	(44.0)	65	(39.6)
Overweight	0	(0.0)	2	(1.6)	6	(3.2)	16	(9.1)	24	(18.8)	41	(20.6)	40	(34.5)	37	(22.6)
Obesity	0	(0.0)	0	(0.0)	3	(1.6)	8	(4.6)	1	(0.8)	26	(13.1)	15	(12.9)	48	(29.3)
Markers for weight status [Mean (SD)]																
BMI (z-score)[‡]	−1.6	(1.0)	−1.4	(1.1)	−1.1	(1.2)	−0.5	(1.4)								
BMI									22.0	(3.5)	23.6	(5.0)	24.6	(4.5)	26.5	(6.9)
Body fat (in %)	14.9	(3.6)	14.6	(4.8)	10.5	(5.3)	20.4	(7.5)	15.6	(8.1)	27.9	(10.5)	21.7	(7.4)	34.3	(9.7)
Waist circum-ference (in cm)	50.4	(5.7)	49.5	(5.8)	62.7	(9.8)	64.9	(10.8)	76.4	(9.0)	78.7	(13.5)	87.1	(13.9)	88.6	(15.4)
Urinary excretion [Mean (SD)]																
Sodium (in mEq/day)[§]	181.7	(69.5)	139.7	(51.2)	191.6	(71.1)	168.5	(58.7)	196.4	(101.0)	172.5	(67.3)	182.2	(70.4)	178.3	(62.7)
Potassium (in mEq/day)[§]	36.4	(17.8)	27.9	(12.9)	40.1	(21.4)	33.4	(14.0)	38.7	(18.6)	36.9	(22.1)	38.8	(20.0)	36.5	(15.2)
24 h sodium- to-potassium ratio	5.4	(1.7)	5.6	(2.4)	5.3	(1.7)	5.4	(1.6)	5.3	(1.6)	5.1	(1.7)	5.1	(1.4)	5.2	(1.4)
Creatinine (in mg/ml)[‖]	1.4	(1.0)	1.3	(0.9)	1.8	(1.3)	1.4	(1.0)	2.2	(1.3)	1.6	(1.1)	2.0	(1.2)	1.4	(1.1)
Education [*N* (%)][¶]																
None or primary	25	(18.7)	29	(22.8)	28	(15.1)	16	(9.1)	22	(17.3)	57	(29.5)	52	(46.4)	92	(56.8)
Secondary or higher	109	(81.3)	98	(77.2)	158	(85.0)	159	(90.9)	105	(82.7)	136	(70.5)	60	(53.6)	70	(43.2)
Area of residence [*N* (%)]																
Rural	68	(50.8)	58	(45.7)	101	(54.3)	72	(41.1)	49	(38.3)	94	(47.2)	57	(49.1)	83	(50.6)
Urban	66	(49.2)	69	(54.3)	85	(45.7)	103	(58.9)	79	(61.7)	105	(52.8)	59	(50.9)	81	(49.4)

SBP, Systolic blood pressure; DBP, diastolic blood pressure, BMI, body mass index.
[*]According to NIH (children) (23) and National Heart Foundation (adults) classification (24).
[†]According to WHO classifications (21).
[‡]BMI z-score was calculated according to WHO (21).
[§]Estimated urinary excretion was determined from a fasting morning urine specimen on the basis of the Kawasaki formula (26).
[‖]Measured creatinine from single morning spot specimen.
[¶]According to UNESCO classification of educational levels (16). For children: highest education in household.

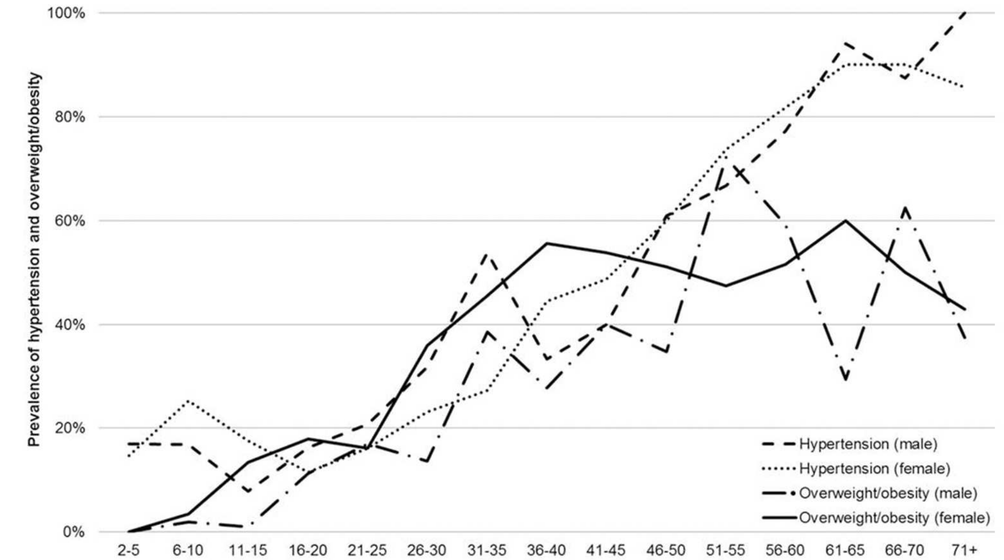

FIGURE 2 | Prevalence of hypertension and of overweight/obesity.

associated with an increased chance for hypertension as well. Only severe thinness in children <19 years was found to be preventive regarding high blood pressure. Whereas, models for WC and %BF seems to correlate for the adult population (**Figure 3**), they were less precise in young (2–≤ 9 years) and in older children (>9–≤ 19 years), due to a small number of hypertensive participants and a high prevalence of underweight in these age-groups. Furthermore, WC and %BF as indicator for weight status did not correlate with weight status compared to BMI in our sample: children with (severe) thinness, which were possibly suffering from severe acute malnutrition, such as diseases like Marasmus or Kwashiorkor and might have mislead the classification for markers of weight status due to an altered body composition (35). Additionally, the small sample size may have prevented us from detecting an association between weight status and hypertension in these age-groups.

Since interventions on salt reduction in Sub-Sahara Africa resulted in improved outcome measures of blood pressure and urinary sodium excretion (14), we furthermore expected an association between sodium-to-potassium ratio (as substitute for salt intake) and hypertension in our sample. Previous studies reported that high intake of salt (36–39), especially sodium, was associated with hypertension (40), whereas potassium seemed to act as a preventive factor (41). But contrary to previous findings, we observed a significant decreased hypertension chance associated with a high sodium-to-potassium ratio (higher sodium than potassium excretion) in the age-group >9–≤ 19 years. In addition, we observed that a high sodium-to-potassium ratio reduce chance of hypertension (OR < 1) in young children (2–≤ 9 years) and children (>9–≤ 19 years) as mentioned, but in young adults (>19–≤ 40 years) no association was found, while a high sodium-to-potassium ratio was found to be apparent associated (OR > 1) with hypertension in adults (>40 years). However, these results should be interpreted carefully. A lower excretion of potassium than sodium in children does not necessarily indicate lower potassium intakes. Potassium is needed especially in somatic growth (42) and can therefore affect the sodium-to-potassium ratio in urine. However, we could not provide a reasonable justification for the observed positive association between lower potassium excretion and a decreased chance of hypertension. Further influencing factors like genetic predispositions (43–47) and early life origins (48, 49) should be taken into consideration.

We observed a considerable amount of unexplained variance on the Shehia level, which was more pronounced in children than in adults (see **Table 2**). Urban and rural areas often differ in topography, distances to daily supplies, access to food and medical services as well as sources of income. Due to the random distribution of Shehias throughout Zanzibar, such area and Shehia level confounders were not measured.

Regarding strengths and limitations, this survey is one of the first ones including an exhaustive study protocol on Zanzibar, Tanzania. It covers anthropometric measurements and biochemical markers of all age-groups in different regions of Unguja Island. Unfortunately, proportion of children <5 years of age per household was lower than expected (50) which may have attenuated the effects for the age-group 2 to ≤ 9 years (mean age 11 years) due to a smaller sample size. The full sample included individuals from households and Shehias that were both randomly selected. We thus assume that the study sample characterizes the Zanzibari population. Additionally, using the Kawasaki formula we were able to consider creatinine concentration of the urine sample provided, which is a clear strengths of our study. We also investigated a possible non-linear association between the sodium-to-potassium ratio and blood pressure in the subsample of salt

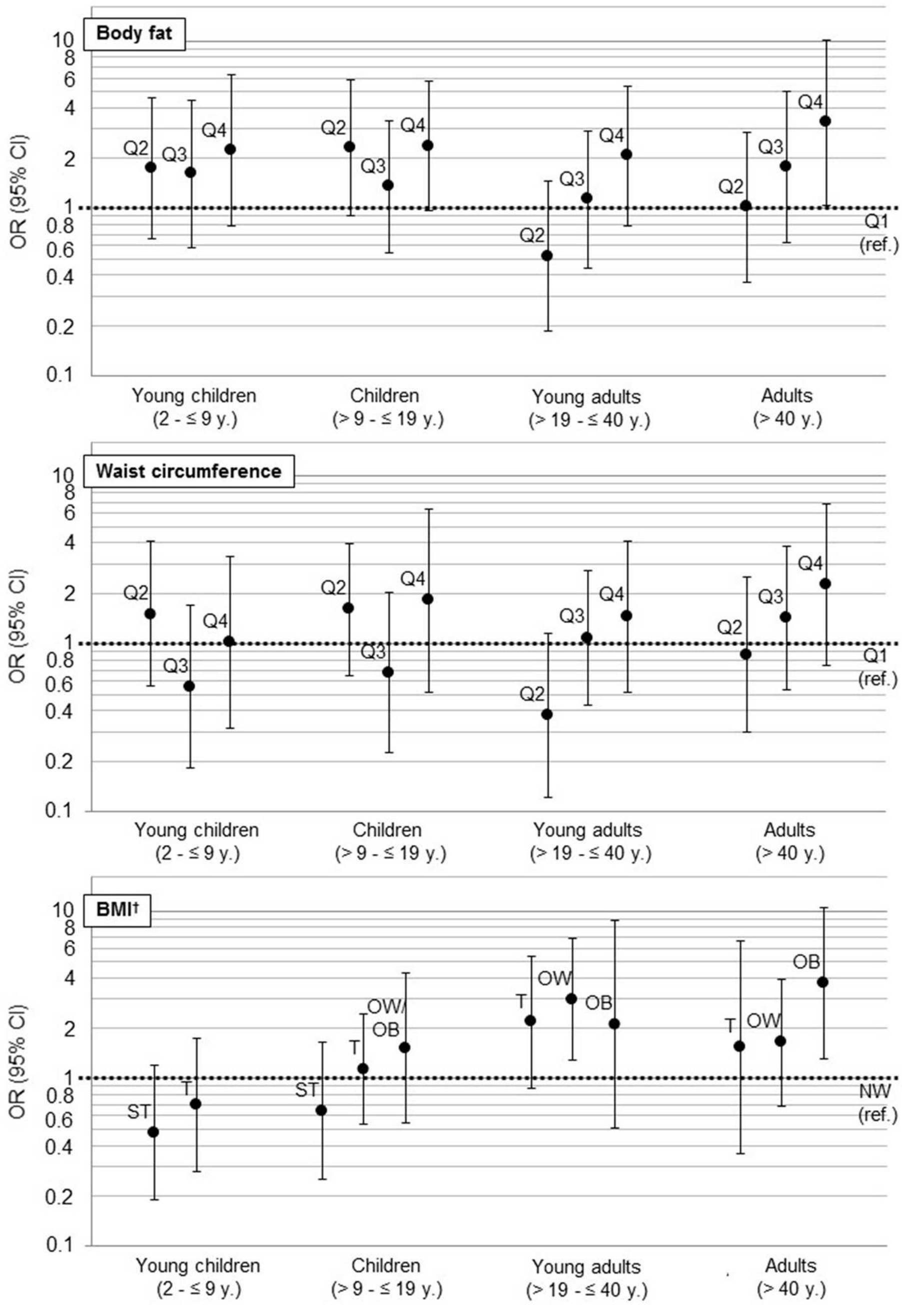

FIGURE 3 | Association of anthropometric markers (WC, BF, BMI, ref: first Quartile) with hypertension as results from multilevel logistic regressions (hypertension: according to NIH (children) (23) and National Heart Foundation (adults) classification (24). For children: hypertension and prehypertension (25)). For a better visual comparison regarding the magnitudes of confidence intervals, we used a log scale. OR, Odds Ratio; CI, confidence interval; ref., reference; BMI, Body mass index; ST, severe thinness; T, thinness; NW, normal weight; OW, overweight; OB, obesity. †BMI z-score for children was calculated according to WHO (21).

intake (results not shown). However, in sensitivity analyses cubic regression splines fitted similarly compared to a simple linear univariate regression; thus, we kept the originally conducted linear regression models.

Since the study was performed in a cross-sectional design, it is not possible to attribute the observed significant associations as causal. Therefore, we suggest confirming the reported findings using longitudinal data of a comparable study population. Furthermore, other possible determinants like physical activity could not be taken into account. Although physical activity was measured in this study by uniaxial accelerometer, we did not use the data in our analysis. Data were available only for a

TABLE 2 | Associated factors with hypertension* detected in multilevel logistic regression models stratified by age.

Model	*N*	OR (95% CI)				BIC	Between Shehia Variance (SE)	
		Marker for weight status		Sodium-to-potassium ratio				
Young Children (2–≤ 9 years)								
Model 1(a): Bodyfat	170			1.0	(0.9, 1.2)	174.1	1.5	(0.5)
Q1		1	(Ref.)					
Q2		1.7	(0.7, 4.6)					
Q3		1.6	(0.6, 4.4)					
Q4		2.2	(0.8, 6.3)					
Model 1(b): Waist circumference	172			1.0	(0.9, 1.2)	170.3	1.5	(0.5)
Q1		1	(Ref.)					
Q2		1.5	(0.6, 4.1)					
Q3		0.6	(0.2, 1.7)					
Q4		1.0	(0.3, 3.4)					
Model 1(c):BMI†	172			1.0	(0.9, 1.2)	161.0	1.5	(0.4)
Severe thinness		0.5	(0.2, 1.2)					
Thinness		0.7	(0.3, 1.7)					
Normal weight		1	(Ref.)					
Children (>9–≤ 19 years)								
Model 2(a): Bodyfat	244			**0.7**	**(0.6, 0.9)**	311.3	1.1	(0.4)
Q1		1	(Ref.)					
Q2		2.3	(0.9, 5.9)					
Q3		1.3	(0.5, 3.3)					
Q4		2.4	(1.0, 5.8)					
Model 2(b): Waist circumference	244			**0.7**	**(0.6, 0.9)**	316.0	1.2	(0.4)
Q1		1	(Ref.)					
Q2		1.6	(0.7, 4.0)					
Q3		0.7	(0.2, 2.0)					
Q4		1.8	(0.5, 6.4)					
Model 2(c): BMI†	246			**0.7**	**(0.6, 0.9)**	320.4	1.2	(0.4)
Severe thinness		0.6	(0.2, 1.7)					
Thinness		1.1	(0.5, 2.4)					
Normal weight		1	(Ref.)					
Overweight/obesity		1.5	(0.5, 4.3)					
Young Adults (>19–≤ 40 years)								
Model 3(a): Bodyfat	198			1.0	(0.8, 1.2)	264.6	1.0	(0.4)
Q1		1	(Ref.)					
Q2		0.5	(0.2, 1.5)					
Q3		1.1	(0.4, 2.9)					
Q4		2.0	(0.8, 5.4)					
Model 3(b): Waist circumference	199			1.0	(0.8, 1.2)	266.7	1.1	(0.4)
Q1		1	(Ref.)					
Q2		0.4	(0.1, 1.2)					
Q3		1.1	(0.4, 2.7)					
Q4		1.4	(0.5, 4.0)					
Model 3(c): BMI	199			1.0	(0.8, 1.3)	265.6	1.1	(0.4)
Thinness		2.2	(0.9, 5.4)					
Normal weight		1	(Ref.)					
Overweight		**3.0**	**(1.3, 6.8)**					
Obesity		2.1	(0.5, 8.7)					

(Continued)

TABLE 2 | Continued

Model	*N*	OR (95% CI)				BIC	Between Shehia Variance (SE)	
		Marker for weight status		Sodium-to-potassium ratio				
Adults (>40 years)								
Model 4(a): Bodyfat	186			1.3	(1.0, 1.7)	225.4	0.9	(0.5)
		1	(Ref.)					
		1.0	(0.4, 2.9)					
		1.8	(0.6, 5.0)					
		3.3	**(1.0, 10.1)**					
Model 4(b): Waist circumference	186			1.2	(0.9, 1.6)	227.6	1.0	(0.5)
		1	(Ref.)					
		0.9	(0.3, 2.5)					
		1.4	(0.5, 3.9)					
		2.2	(0.7, 6.8)					
Model 4(c): BMI	187			1.3	(1.0, 1.7)	224.7	0.9	(0.5)
Thinness		1.6	(0.4, 6.6)					
Normal weight		1	(Ref.)					
Overweight		1.6	(0.7, 4.0)					
Obesity		**3.7**	**(1.3, 10.5)**					

All models were adjusted for age, sex, height [height for age for children ≤ 19 years (WHO)] and education (primary school and below was categorized as low and secondary school and above as high education (16); for children highest education was used as proxy). Random effects on Shehia level were considered.
OR, Odds Ratio; CI, confidence interval; BIC, Bayesian information criterion; SE, Standard Error, BMI, Body mass index.
**According to NIH (children) (23) and National Heart Foundation (adults) classification (24). For children: hypertension and prehypertension (25).*
†BMI z-score was calculated according to WHO (21). Bold numbers are statistically significant.

small subsample of children and adolescents, aged between 3 and 16 years, which were randomly selected from 20 Shehias for these measurements. Additionally, there is always a degree of uncertainty with regard to fasting status of participants for at least 12 h prior to collection of biological samples. However, self-collection of urine potentially affected our data.

Assessing plausible salt intakes is difficult. We therefore decided to use urinary excretion of sodium and potassium as surrogates. Even if previous research indicates that urinary excretion could be used as surrogate for salt intake (51), a difference between intake and excretion cannot be ruled out completely. To our knowledge, there are no existing formulas to calculate 24 h salt excretions from single morning spot urine that were validated in a sub-Sahara African population for adults as well as for children. We conducted sensitivity analyses using the formulas from Kawasaki et al. (26), from Tanaka et al. (52) and from INTERSALT (53). We did not observe remarkable differences in results when applying different formulas on our study data (data not shown). We decided to use the Kawasaki formula (26), since a consideration of both sodium and potassium is possible using this method.

The interpretation of the association between hypertension and salt excretion from a single measurement had to be considered carefully, since previous studies showed that four to seven urine specimens are needed to estimate sodium-to-potassium ratio in hypertensive individuals (54).

CONCLUSION

Despite the limitations this study to our knowledge is the first to report such associations in a randomly selected population using standardized assessment of anthropometrical and laboratory measurements in Zanzibar.

High blood pressure among Zanzibaris is positively associated with BMI and body composition in >19–95 year olds and is negatively associated with salt intake in >9–≤ 19 year olds. Still, there is a tendency that salt intake increases hypertension chance in the age-group 40 years and above. Promotion strategies to reduce hypertension prevalence among Zanzibaris should consider healthy weight maintenance and strategies that facilitate appropriate salt intakes for the population.

For the future, a reduction of the high hypertension prevalence is of high public health interest. There is a need for effective interventions to prevent long-term effects of hypertension and for primary prevention strategies to tackle the rising prevalence using local multidisciplinary approaches considering local lifestyles and eating habits in the local language, Swahili. Continuation of health surveillance initiatives will help to monitor health prevention activities in future. Furthermore, practicing physicians and health professionals should proactively advice and teach patients self-care skills in diet for weight maintenance or weight loss to prevent development of cardiovascular diseases.

ETHICS STATEMENT

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. The study was performed according to the Helsinki Declaration and the study protocol was evaluated and approved by the Ethics Committees of the University of Bremen and of the Zanzibar Ministry of Health and the Zanzibar Medical Research and Ethics Committee. Study participants did not undergo any procedures unless both children and their parents had given consent for examinations, collection of samples, subsequent analysis and storage of personal data and collected samples. Study subjects could consent to single components of the study while abstaining from others. All participants agreed and signed that the data collected during the survey can be stored and used for future analysis.

AUTHOR CONTRIBUTIONS

AH was a principal investigator and had the idea of the analysis. LB wrote the paper and had primary responsibility for final content. CB provided advise for the data analysis. MN involved in the development of the instruments and was responsible for the survey and data management. LB, CB, MN, AH, SK, and MS were responsible for critical revisions and final approval of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2019.00338/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.