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FOOD SECURITY AND NUTRITIONAL STATUS OF WOMEN SHELLFISHERS AND THE POTENTIAL ROLE OF OYSTERS AS A SOURCE OF DIETARY MINERALS AND HEAVY METALS IN THREE ESTUARINE SITES IN GHANA

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BY

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DECLARATION

I, Francis Zinenuba Taabia, hereby declare that this thesis for a Doctoral degree is entirely my original work produced from research under the following supervisors.

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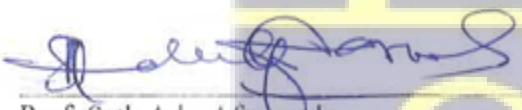

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DEDICATION

I would like to dedicate this report to my beloved wife, Bertilla R. Yussif, and our children, Hereigns M. Taabia, Tray M. Taabia, and Mishael C. T. Taabia.

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ABSTRACT

Background: Food insecurity in Ghana has significantly worsened over the past decade, leading to rising hunger and malnutrition, particularly among women. Thus, the Food and Agricultural Organization recommends integrating local food systems into food and nutrition security efforts. In Ghana's coastal communities, oysters are valuable food resource and could offer an affordable source of protein and essential micronutrients like iron and zinc and thereby improve women's food security and nutritional status (anaemia and overweight/obesity). However, pollution and ecosystem degradation threaten sustainable oyster production and could impact women's food security, anaemia and overweight/obesity status in these communities. This study aimed to compare the household food insecurity, dietary intake, anaemia, and overweight/obesity among women of reproductive age engaged in oyster harvesting, processing, and retailing (hereafter, women shellfishers) at three selected estuarine sites in Ghana. Additionally, the study aimed to determine the factors associated with household food insecurity, anaemia and overweight/obesity status and assess the potential of oysters as a source of dietary minerals for women shellfishers at the three estuarine sites.

Methods: This cross-sectional study was conducted at three estuarine sites: Bortianor-Tsokomey-Tetegu area in the Greater Accra Region (Densu estuary), New Amanful-Apremdo-Beahu area in the Western Region (Whin estuary), and Ekumfi Narkwa in the Central Region (Narkwa Lagoon). A total of 504 women shellfishers were recruited across the three selected sites. Data on household characteristics, food insecurity, and dietary intake were collected using a structured questionnaire and repeated 24-hour dietary recalls. Overweight/obesity (≥25 kg/m^2), and anaemia (<12 g/dl) status were assessed through anthropometric measurements and capillary blood samples. Additionally, 915 oyster samples from the three selected sites were analysed for

mineral composition using atomic absorption spectrometry. Descriptive statistics were used to summarise participants' characteristics and the mineral consents of the oysters. Chi-Square test was used to compare the rates of anaemia, overweight/obesity, household food insecurity, and nutrient inadequacies (iron, zinc, calcium, magnesium, potassium, and phosphorus) across the sites, while multiple logistic regression models were used to determine the factors associated with anaemia, overweight/obesity, and household food insecurity in separate models at a statistical significance of 0.05. The mean mineral contents of oysters were compared across the three sites using ANOVA. Health risks related to oyster consumption of the women shellfishers were evaluated using the Hazard Index (HI) and Cancer Index (CI). Ethics approval was obtained from the Ghana Health Service (GHS-ERC 015/12/20).

Results: The mean ± SD age of the women shellfishers was 31.6 ± 9.1 years. The women had a mean ± SD of 4.9 ± 4 years of schooling, with 44.8% identified as literate. A slight majority were married (61.3%). The average household size was 6, and the household poverty probability index for the study population was 13%. Household food insecurity prevalence was high across all sites, recorded at 93.5% at the Densu estuarine site, 93.1% at the Narkwa Lagoon site, and 88.5% at the Whin estuarine site, with no statistically significant differences observed between sites ($p = 0.218$). In contrast, the prevalence of overweight/obesity varied significantly across sites, with rates of 58.3% at Densu, 43.1% at Whin, and 27.6% at Narkwa Lagoon ($p < 0.001$). Anaemia prevalence also differed significantly across sites, with 25% at Densu, 20% at Narkwa Lagoon, and 15% at Whin ($p = 0.025$). Residing in the Densu site, compared to the Whin site, was significantly associated with increased odd of household food insecurity (aOR=3.14, CI: 1.18-8.33; p=0.022). However, a unit increased in household assets was significantly associated with reduced odd of household food insecurity (aOR=0.73, CI: 0.54-0.98; p=0.037). The odds of overweight/obesity

were 70% lower in women under 25 years compared to those aged 45 years and older (aOR=0.30, CI: 0.11–0.85; p=0.006). Married women had nearly twice the odds of being overweight/obese compared to those who were never married (aOR=1.93, CI: 1.07–3.30; p=0.027). An increase in household poverty rate was associated with reduced odds of overweight/obesity (aOR=0.97, CI: 0.95–0.99; p=0.011). Women in the middle tertile of nutrient-rich dietary patterns had nearly double the odds of being overweight/obese compared to those in the lower tertile (aOR=1.68, CI: 1.01–2.78; p=0.046). The odds of anaemia were lower in overweight (aOR=0.56, CI: 0.32–0.98; p=0.041) and obese (aOR=0.27, CI: 0.12–0.61; p=0.002) women compared to those with normal weight. Residing in the Densu site, compared to the Whin site, was significantly associated with twice the odds of anaemia (aOR=2.24, CI: 1.20–4.18; p=0.012). However, no significant association was found between oyster intake and the odds of anaemia (aOR=1.58, CI: 0.83–3.02; p=0.168). The women's average caloric intake differed significantly across sites, with values of 1377 kcal at Densu, 1470 kcal at Whin, and 1592 kcal at Narkwa Lagoon (p=0.011). Iron intake was similar across sites, with averages of 9.4 mg at Densu, 9.1 mg at Narkwa Lagoon, and 9.4 mg at Whin (p=0.858). Average zinc intake also showed no significant variation, recorded at 6.4 mg for Densu, 5.6 mg for Narkwa Lagoon, and 5.9 mg for Whin (p=0.121). Oyster consumption contributed 17.2% (1.6 mg/day) of the average daily iron intake and 18.3% (1.1 mg/day) of the average daily zinc intake. The prevalence of nutrient inadequacy, assessed across six nutrients, showed no significant variation among sites, with rates of 91.5% at Densu, 90.0% at Whin, and 94.8% at Narkwa Lagoon (p=0.240). The mean mineral concentrations (mg/kg wet weight) in the oysters were potassium (4282), phosphorus (3470), calcium (2698), and magnesium (937), iron (120.5), zinc (82.4), chromium (22.1), copper (8.5), manganese (7.2), and selenium (5.4). Heavy metal concentrations were arsenic (0.102), mercury (0.038), cadmium (0.037), and lead (0.032).

The Hazard Index (HI) ranged from 0.0004 to 1.81 (mean 0.071), indicating low health risks. The Cancer Index (CI) for arsenic, cadmium, and lead ranged from 1.3×10^{-6} to 5.8×10^{-4}, suggesting minimal cancer risk. Selenium provided notable nutritional benefits, with a health benefit value ranging from 0.05 to 94.44 (mean 5.38).

Conclusion: The study found high prevalence of household food insecurity and overweight/obesity among women shellfishers, along with inadequate intake of key micronutrients like iron and zinc. Oysters were found to be valuable sources of dietary minerals. These findings highlight the need for targeted interventions to improve access to nutritious foods, raise awareness of dietary needs, and address both food insecurity and obesity. The study recommends that nutrition education and obesity prevention be integrated into reproductive health services to tackle the dual burden of malnutrition and improve well-being.

Key words: oysters, women shellfishers, nutrient inadequacies, food insecurity, obesity.

TABLE OF CONTENTS

LIST OF FIGURES/MAPS

LIST OF TABLES

LIST OF ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome.
BMI	Body Mass Index
CFSVA	Comprehensive Food Security and Vulnerability Analysis
CI	Cancer Index
DALYs	Disability-Adjusted Life Years
DHS	Demographic and Health Surveys
DOPA	Densu Oyster Pickers' Association
FAO	Food and Agricultural Organization
FiS	Food Insecurity
GDHS	Ghana Demographic and Health Surveys
GLSS	Ghana Living Standards Survey
GNR	Global Nutrition Report
Hb	Haemoglobin
HI	Health Index
HIV	Human Immunodeficiency Virus.
HM	Heavy Metals
IPA	Innovation for Poverty Action
LMIC	Low-and-Middle-Income Countries
MDD-W	Minimum dietary diversity of women
MoFA	Ministry of Food and Agriculture
NHIS	National Health Interview Survey
RCT	Randomized Controlled Trial
RDA	Recommended Dietary Allowance
SSA	sub-Saharan Africa
SWAC	Sahel and West Africa Club
TCR	Target Cancer Risk
TDI	Tolerable Daily Intake
UG	University of Ghana
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WBG	World Bank Group

WFP	World Food programme
WHO	World Health Organization
WRA	Women of Reproductive Age

ORGANIZATION OF THE THESIS

The thesis is organized as follows:

PART ONE: INTRODUCTION AND LITERATURE REVIEW

Chapter 1: Introduction and justification of the research

Chapter 2: A literature review

PART TWO: STUDY OBJECTIVES AND METHODOLOGY

Chapter 3: Study objectives

Chapter 4: Description of the methodology

PART THREE: RESULTS ADDRESSING THE SPECIFIC OBJECTIVES

Chapter 5: Results addressing the first specific objective, presented in journal-style format

Chapter 6: Results addressing the second specific objective presented in journal-style format

Chapter 7: Results addressing the third specific objective presented in journal-style format

Chapter 8: Results addressing the fourth specific objective presented in journal-style format

PART FOUR: DISCUSSION AND CONCLUSION

Chapter 9: Summary discussion and conclusion of all the findings presented in Part Three

PART ONE: INTRODUCTION AND LITERATURE REVIEW

CHAPTER 1: Introduction and Justification of the Research

1.1 Background

Food insecurity remains a critical global challenge, leading to limited access to nutritious diets and contributing to rising levels of hunger and malnutrition (FAO et al., 2024). This situation exacerbates deficiencies in essential macro- and micronutrients, affecting health outcomes across populations (GPAFSN, 2016; WHO, 2020). This issue is particularly acute in developing regions, where food insecurity leads many to rely on inexpensive, high-calorie foods, exacerbating malnutrition (FAO, 2021b). To address these challenges, the Food and Agricultural Organization (FAO) have recommended integrating local food systems into nutrition security initiatives. Ethnographic food resources, such as oysters, play a critical role in enhancing food security for coastal communities (Agbekpornu et al., 2021; Dias et al., 2022). Oysters are not only an affordable source of dietary protein but also rich in essential micronutrients like iron and zinc, which are critical for overall well-being and reproductive health. A serving of raw oysters (100 g) provides 39.3 mg of zinc and 8 mg of iron (NIH, 2022b; USDA, 2020a), fulfilling over 100% of the Recommended Dietary Allowance (RDA) for zinc (8 mg/day) and 44% of the RDA for iron (18 mg/day) for women of reproductive age (NIH, 2022b). In addition to zinc and iron, oysters are a valuable source of other dietary minerals like selenium (19.7 ug) and copper (2.86 mg), and essential omega-3 polyunsaturated fatty acids (0.55 mg) per 100 g, which support heart health, neurodevelopment, and maternal health for women of reproductive age (Asha et al., 2014; Willer & Aldridge, 2019; Yoda et al., 2021). As a result, oysters can be instrumental in addressing micronutrient deficiencies, particularly iron-deficiency anaemia, which affects 35% to 58% of women in West Africa (GMS, 2017; Stevens et al., 2022; SWAC, 2019).

In Ghana, an estimated 4,000 individuals, mostly women, participate in the oyster value chain, engaging in harvesting, processing, and retailing shellfish (Chuku et al., 2020; Osei et al., 2021a). This activity not only contributes significantly to household income but also has the potential to enhance food security due to the high nutrient content of oysters. However, despite the importance of oysters in these communities, their nutritional potential remains underexplored in Ghana. Micronutrient deficiencies, such as anaemia, have persisted among women of reproductive age for decades, with little improvement (Ecker & Van Asselt, 2017; GMS, 2017). Additionally, there is limited research on how shellfish harvesting activities impact the food security and nutritional status of women shellfishers.

Current data on the mineral content of mangrove oysters comes primarily from studies conducted outside of Africa, particularly in the United States and China. However, nutrient concentrations may differ in West Africa due to variations in geographic locations, species and maturity (Greenfield & Southgate, 2003). Furthermore, the few studies on oysters conducted in Africa have often been based on small sample sizes, making it difficult to accurately capture the variability of micronutrients in biological samples (Greenfield & Southgate, 2003). Understanding the mineral composition of local oysters is critical for developing public health guidelines and promoting oysters as a nutrient-rich food source in coastal communities. At the same time, the mangrove ecosystems that support oyster production are under threat from human activities, such as improper waste disposal, agricultural chemicals, and artisanal mining (Chuku et al., 2020; Osei et al., 2021a). These activities introduce contaminants into the water, potentially leading to the accumulation of heavy metals in oysters, which could pose serious health risks to consumers (Nour, 2020a; Zhu et al., 2020). Oysters, as filter feeders, can absorb toxins from their surroundings, and consumption of contaminated oysters can lead to liver and kidney damage,

toxicity, and even cancer (Lin et al., 2013; Yousaf et al., 2016). Therefore, ensuring the safety of oysters for consumption is crucial for protecting public health in these communities. Therefore, the study sought to assess the food security and nutritional status of women shellfishers, as well as the potential role of oysters as a source of dietary minerals in three estuarine sites in Ghana.

1.2 Problem Statement

Globally, food insecurity is on the rise, with overnutrition linked to the consumption of high-calorie, low-nutrient foods becoming more prevalent, particularly in developing regions (FAO, 2021b; Global Nutrition Report, 2021). This trend has been worsened by the COVID-19 pandemic, which disrupted food supply chains, led to job losses, and reduced household incomes (Adusei, 2021; Ayanlade & Radeny, 2020; WFP et al., 2020). As a result, 30.4% of the global population lacks sufficient access to food, with Asia and Africa disproportionately affected. In Africa, food insecurity affects over 60% of the population, particularly in West Africa (FAO, 2021b). Ghana, like many developing countries, suffers from chronic food insecurity, heavily relying on food imports (Armah et al., 2011; Raheem et al., 2021). Recent data in Ghana indicates that food insecurity has more than doubled in the last decade (CFSVA, 2022). Among women of reproductive age, 23% experience food insecurity, with female-headed households also disproportionately affected (CFSVA, 2022; Pobee et al., 2020). Fishing households, particularly along Ghana's coastal regions, are especially vulnerable, with 10.9% experiencing food insecurity, rising to 19% in the Central region (Asuru, 2020). Women, who play critical roles in agriculture and fishing, bear the brunt of food insecurity, especially as declining mangrove health and fish populations threaten their livelihoods (Chuku et al., 2020).

Food insecurity has a direct link to undernutrition, with Africa's undernourished population accounting for 21% globally (FAO, 2021b; Global Nutrition Report, 2021). In fishing communities, up to 55% of adults are undernourished (Pal et al., 2011). At the same time, overweight and obesity rates are rising, with 21% and 12% of African adults being overweight or obese, respectively (Global Nutrition Report, 2021a). In Ghana, overweight and obesity disproportionately affect women of reproductive age, with prevalence ranging from 40.4% to 50%, compared to 21% in men (Ecker & Van Asselt, 2017; GDHS, 2024). In rural areas, this disparity is even more pronounced, contributing to poor reproductive health outcomes and heightened risks of micronutrient deficiencies (Bailey et al., 2015; Kim et al., 2017). Micronutrient deficiencies, particularly in zinc and iron, remain critical public health concerns in Ghana and other West African coastal countries due to their roles in reproductive health and preventing maternal and neonatal mortality (Bailey et al., 2015). Anaemia affects 21.7–34% of Ghanaian women, while 15% suffer from zinc deficiency (Gernand et al., 2017). Despite efforts, the adoption of supplementation programmes has not sustainably reduced these deficiencies (GDHS, 2014; WHO, 2020). Women in fishing communities are especially vulnerable, with multiple micronutrient deficiencies affecting 28% of women in Ghana (Pobee et al., 2020). Oysters, a traditional food source in coastal communities, present a potential solution for addressing micronutrient deficiencies due to their high mineral content (Chuku et al., 2020; FAO, 2019). However, limited research has been conducted on their role in African diets. Additionally, mangroves, which produce oysters, are increasingly threatened by anthropogenic activities, and there are concerns about heavy metal contamination in oysters. Given the reliance on oysters as a food source in these communities, assessing both their nutritional benefits and potential health risks is critical for improving food security and nutrition among women shellfishers in coastal Ghana.

1.3 Rationale of the Study

The coastal belt of Ghana faces significant food insecurity and livelihood challenges, especially among fishing and shellfish-dependent households Many women living in coastal communities are under pressure of food insecurity due to degradation of their mangrove and estuarine ecosystem, leading to declining fish stocks and economic disruptions of their shell-fishing value chain (CFSVA, 2022; Chuku et al., 2020). he effects of these challenges are particularly pronounced for women shellfishers, whose livelihoods are contingent upon estuarine ecosystems and the seasonal harvesting of oysters. Among African coastal countries, women constitute approximately 79% of shellfish harvesters. In Ghana, it is estimated that 88% of estuarine and mangrove ecosystem-based shellfish harvesters are women. A study conducted in communities adjacent to estuarine sites revealed that a majority (63%) of these women were engaged in oyster harvesting (Chuku et al., 2022). However, these livelihoods are increasingly jeopardised due to mangrove degradation, pollution, and overexploitation, which diminish the availability of oysters and, consequently, income. This situation has resulted in a dual burden for women, characterised by reduced household income and increased food insecurity, thereby compromising both access to food and the nutritional quality of diets. Oysters, rich in protein and essential micronutrients like iron and zinc, are vital for food security in coastal communities. However, data on their nutritional composition in Ghana and West Africa is limited, and the contribution of oyster consumption to addressing micronutrient inadequacies or deficiencies among women of reproductive age remains unknown. Additionally, there is limited research on potential health risks, such as heavy metal contamination from polluted estuarine environments. These knowledge gaps hinder the development of policies and programmes that could enhance both livelihood empowerment and nutritional improvement among women in coastal

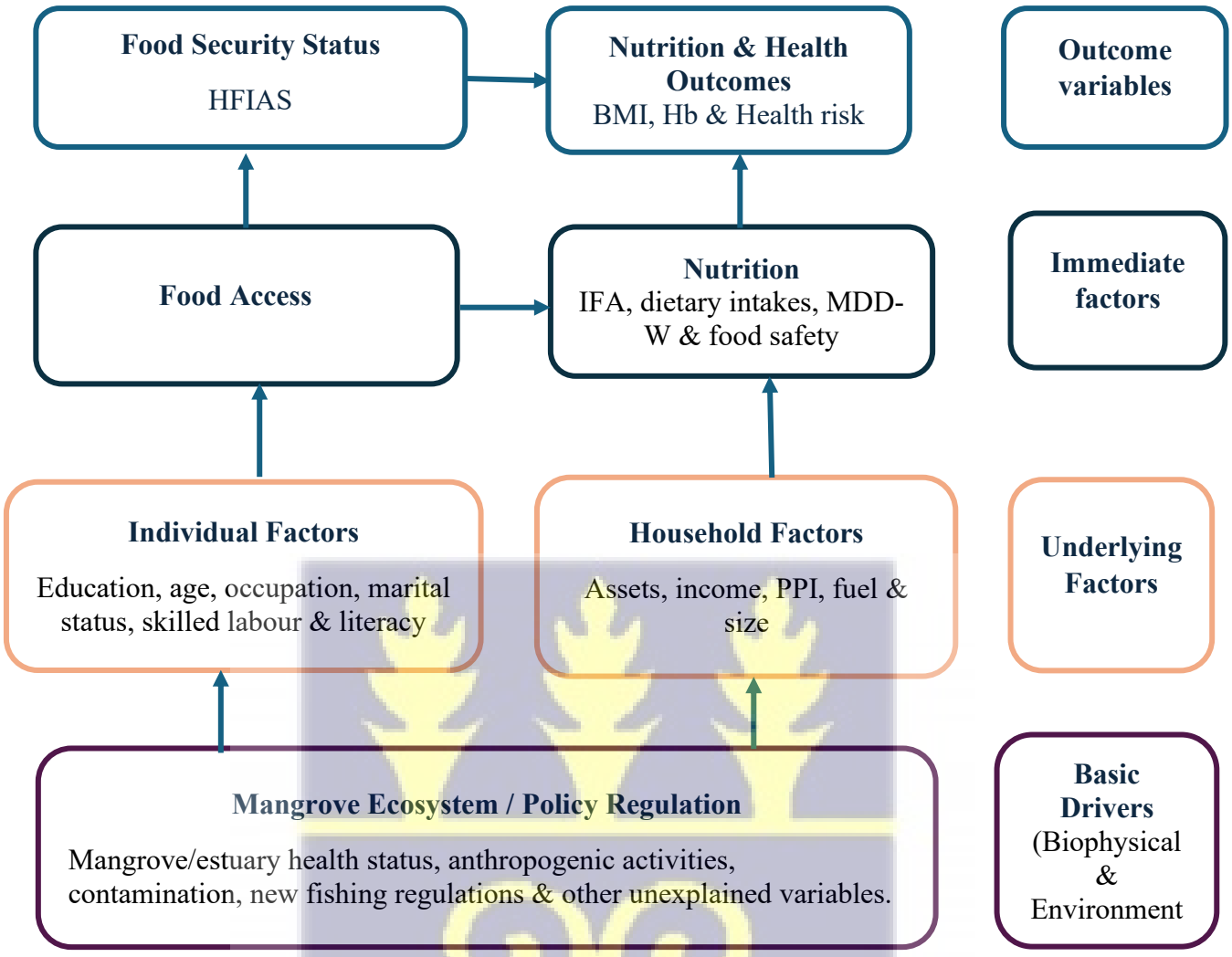
communities. This study sought to address these gaps by assessing the role of oyster consumption in dietary mineral intake and evaluating potential health risks, including contamination, while examining the food security and nutritional status of women shellfishers along three estuarine sites in Ghana.

1.4 Significance of the Study

The COVID-19 pandemic has worsened food insecurity and malnutrition, particularly among vulnerable groups like women. This study was conducted between June 2021 and December 2021, is crucial for understanding the food security status, nutrition, and dietary patterns of vulnerable subgroup such as women shellfishers in coastal Ghana when the country was emerging from COVID-19 era restrictions. It provides insights into the extent of food insecurity and highlights the potential of oysters as a local, nutrient-rich food source that can help address micronutrient inadequacies or deficiencies, particularly in iron and zinc. Additionally, the study explores the health risks associated with heavy metal contamination in oysters, due to artisanal mining and pollution in estuarine sites. These findings can inform policies to promote sustainable shellfish harvesting and ensure the safe consumption of oysters, contributing to both nutrition security and environmental protection.

1.5 Conceptual Framework

The food security of women involved in the shellfish industry is influenced by a range of interconnected issues, which in turn impact their health and nutrition. Figure 1.1 illustrates the linkages when examining the nutrition and potential adverse health outcomes of women involved in estuarine and mangrove ecosystem-based shellfisheries activities. The production and processing of food resources, primarily oysters, depend directly on the mangrove ecosystem and existing sector regulations. These factors constitute the biophysical and environmental drivers of the food system for women in the shellfish industry. Anthropogenic activities such as overfishing, pollution from artisanal mining and agrochemical use, encroachment, and the destruction of mangrove estuaries affect the quantity and quality of their food resources. Chemical contaminations such as arsenic and mercury from unregulated use can impact the survival of fish as well as their nutrient quality for consumption. The biophysical and environmental drivers, in conjunction with underlying factors such as individual and household characteristics, determine how women in the shellfish industry access sufficient and high-quality food, their consumption levels, the safety of their food, and whether they supplement their diet with micronutrients. The resulting indicators include their body mass index and haemoglobin levels, as well as potential health risks (both carcinogenic and non-carcinogenic) associated with the consumption of contaminated oysters. The current framework was informed by the Food and Nutrition Security Framework (FAO et al., 2013) and the UNICEF Conceptual Framework for the Determinants of Malnutrition (UNICEF, 2021), which together explain how food access, utilization, and environmental factors interact to shape nutritional outcomes.



HFIAS, household food insecurity access scale; IFA, Iron folic acid; MMD-W, minimum dietary diversity for women; BMI, body mass index; Hb, haemoglobin; and PPI, probability poverty index.

Figure 1.1: Conceptual framework for how women shell fishing affect nutrition and health outcomes.

CHAPTER 2: Literature Review

2.1 Food Security

Food insecurity, defined as the lack of consistent access to sufficient, safe, and nutritious food, remains a significant global challenge. Recognised as a fundamental human right since 1974 (WFP, 1975), the eradication of hunger and malnutrition was further prioritised in the 2015 Sustainable Development Goals, which aim to achieve zero hunger by 2030 (Ahmed et al., 2017). However, global food insecurity has risen sharply, with over 30% of the global population, or approximately 2.4 billion people, lacking adequate access to food in 2023, a stark increase from 786 million in 1990 (FAO et al., 2023). The problem is particularly pronounced in low- and middle-income countries, especially in Africa and Asia, where food insecurity rates reach 58% and 24.8%, respectively (FAO et al., 2023, 2024). In Sub-Saharan Africa (SSA), 63.3% of the population experienced food insecurity in 2023, with the region bearing the highest global burden (FAO et al., 2024).

In West Africa, food insecurity continues to affect millions, with 274 million individuals experiencing food shortages, despite some regional improvements over the past decade (FAO et al., 2021). Other African nations such as Malawi, Uganda, and Nigeria report food insecurity rates as high as 87%, 88.5%, and 88%, respectively (Ibukun & Adebayo, 2021; Nantale et al., 2017). In Ghana, a developing nation with an agrarian economy, the food insecurity rate in 2020 was 11.7%, affecting approximately 3.6 million people (CFSVA, 2022). While economic growth has improved physical access to food in recent decades (Ecker & Fang, 2016; Van Asselt & Ecker, 2017), significant disparities persist between rural (18.2%) and urban (5.5%) populations (CFSVA, 2022). Regions such as Upper East (48.7%) and Upper West (24%) experience the highest rates of food insecurity, while the Greater Accra region has a lower prevalence (3.5%) (CFSVA, 2022). The

middle ecological zone, Ghana's food production hub, continues to experience food insecurity, with prevalence rates of 42% in Brong-Ahafo and 40% in Ashanti (Bannor et al., 2020).

The impact of COVID-19, coupled with global financial instability and conflict, has further exacerbated food insecurity in Ghana, increasing food costs and disrupting supply chains (FAO & ECA., 2018; FAO et al., 2021). During the pandemic, approximately 69% of Ghanaian households reported experiencing food insecurity (Bukari et al., 2022), highlighting the ongoing vulnerability of the population, particularly in rural and coastal regions. While national data show a reduction in food insecurity, with a decrease from 49.6% in 2018 to 39.4% in 2023 (FAO et al., 2023), disparities between geographic regions and socio-economic groups remain significant. Addressing food insecurity is critical to ensuring equitable access to nutrition and improving global health outcomes.

2.2 Predictors of Food Insecurity

Food insecurity is a multifaceted issue shaped by environmental, agricultural, socio-demographic, and economic factors. This section explores the various contributors to food insecurity, particularly its impact on women, and examines key predictors at the individual and household levels. Environmental challenges, such as climate change and political conflicts, disrupt agricultural productivity, limit access to farmland, and hinder the adoption of necessary technologies. These factors exacerbate food insecurity globally, making it harder for communities to achieve consistent food access. One major factor contributing to food insecurity among women is inequitable access to resources, education, and employment. Women, despite being central to agriculture, often face systemic barriers that reduce productivity and increase the likelihood of food insecurity. Research from Peru (Santos et al., 2022) and Jordan (Bawadi et al., 2012) highlights that female-headed households are especially vulnerable due to limited employment

opportunities in low-paying and informal sectors (Ruel & Alderman, 2013). Gender dynamics within households, influenced by power imbalances and cultural norms, further affect women's access to nutritious food, as shown by studies in Brazil (Felker-Kantor & Wood, 2012) and Ethiopia (Negesse et al., 2020). Educational attainment is also crucial, with higher education levels generally associated with lower food insecurity rates (Santos et al., 2022). However, studies in Uganda (Nantale et al., 2017) and Ghana (Pobee et al., 2020) show that this correlation can vary depending on the local context.

Household size, particularly the presence of children, consistently influences food insecurity. Larger households, especially those with more children, are more vulnerable to food insecurity (Abdu et al., 2018; Felker-Kantor & Wood, 2012). However, findings on the relationship between household size and food insecurity are mixed, with some studies, such as those by Nantale et al. (2017), reporting no significant correlation in Uganda. Parity, or the number of children a woman has, can also impact food security. While some research, like that by Abdu et al. (2018), finds a positive relationship between high parity and food insecurity, others, such as Nantale et al. (2017) and Pobee et al. (2020), show no significant link.

Poverty is one of the most significant predictors of food insecurity, particularly in Africa. Insufficient income limits access to nutritious food, as noted by Smith and Frankenberger (2018). Income inequality exacerbates this issue, particularly in urban settings, where the gap between wealthy and low-income households is stark (Ndlovu et al., 2021). Household wealth is a protective factor, as wealthier households are less likely to experience food insecurity (Pandey & Fusaro, 2020). However, Silvestri et al. (2015) found that while food-insecure households in East Africa had lower per capita incomes, this disparity was not always statistically significant among women. The ownership of domestic assets is another critical factor. Assets such as land and

livestock have been shown to positively influence food security outcomes. However, research by Silvestri et al. (2015) presents a more nuanced view, indicating that certain assets, like stoves and mobile phones, may increase vulnerability to food insecurity among female-headed households in East Africa.

Marital status and ethnicity are also key predictors of food insecurity. Married women generally experience lower food insecurity rates than unmarried women (Dallmann et al., 2023; Pandey & Fusaro, 2020; Pobee et al., 2020). Ethnicity, particularly in countries like Nepal (Pandey & Fusaro, 2020) and Ghana (Koomson & Churchill, 2021), can shape access to food, often through cultural practices like land tenure systems that limit women's access to agricultural land.

In summary, food insecurity is a complex issue with multiple interacting factors, including environmental conditions, socio-economic status, household structure, and gender dynamics. Addressing food insecurity, particularly among women, requires tailored, context-specific interventions that account for the diversity of factors affecting food access. Tackling this global challenge necessitates a nuanced understanding and targeted strategies to improve food security for vulnerable populations.

2.3 Overweight and Obesity in Women

Overweight and obesity, resulting from an imbalance between calorie intake and expenditure, are global health issues with significant physical and mental health risks, including cardiovascular diseases, diabetes, and cancer (Idris et al., 2021; Samodien et al., 2021). The prevalence of overweight and obesity among adult women has risen dramatically, disproportionately affecting women in both developed and developing countries. The World Health Organization WHO (2021a) reports that approximately 55% of women globally are classified as overweight or obese.

In developed regions such as the Americas and Europe, the prevalence is particularly high, with 64.2% of women in the Americas and 59.6% in Europe classified as overweight (Chooi et al., 2019). Turkey has one of the highest rates in Europe, with 81.7% of women overweight or obese (Şahin & Borlu, 2022). Conversely, France reports the lowest rates in Europe (Chooi et al., 2019).

In the Arab world, the prevalence of overweight and obesity among women of reproductive age varies between 20.7% and 80.8%, with the highest rates observed in Iran (Ghorbani et al., 2015) and Libya (Lemamsha et al., 2019). Asia has the lowest prevalence globally, with rates ranging from 4.5% in India to 53.4% in Indonesia (Ghosh et al., 2020). African nations, however, show rapidly increasing rates of overweight and obesity among women, particularly in urban settings. Egypt (83.4%), Ghana (52.4%), and South Africa (68.5%–86%) have some of the highest rates in the region (Amugsi et al., 2017; Ellulu et al., 2014). In Ghana, the prevalence of overweight and obesity among women has surged in recent decades. The Ghana Demographic and Health Survey (GDHS, 2014) reports that more than 50% of women of reproductive age are now classified as overweight or obese, a 40.3% increase from 1993.

Ghana's economic growth has contributed to a shift in dietary patterns, moving from traditional diets to high-calorie, nutrient-dense foods, resulting in higher rates of overnutrition (Ecker & Fang, 2016). The transition from undernutrition to overnutrition, especially in urban areas, has contributed to the growing prevalence of diet-related diseases. Studies highlight a higher prevalence of overweight and obesity in urban women compared to their rural counterparts (Agyemang et al., 2015). Additionally, a study by Aryee et al. (2013) found that approximately one-third of female nurses in northern Ghana were overweight or obese, illustrating the issue's pervasiveness across different occupational sectors.

Regional differences within Ghana reveal significant variations in the prevalence of overweight/obesity. The middle belt has the highest prevalence, ranging from 20% to 75.5% (Kumah et al., 2015; Owusu et al., 2023), followed by the southern belt, where 64.9% of women are classified as overweight or obese (Azize et al., 2021). In contrast, the northern belt shows slightly lower rates, ranging from 33.7% to 55.7% (Amidu et al., 2016; Ofori-Asenso et al., 2016). These disparities reflect regional dietary habits, economic development, and access to healthcare. Additionally, variations based on occupation have been observed, with higher rates of overweight/obesity among professionals in sectors such as healthcare and finance (Addo et al., 2015; Aryee et al., 2013).

In conclusion, overweight and obesity are pressing public health concerns among women, particularly in urban areas and economically transitioning nations like Ghana. The rapid rise in prevalence, combined with regional and occupational variations, calls for targeted interventions to address the growing public health burden associated with overnutrition.

2.4 Predictors of overweight/obesity

Overweight and obesity among women of reproductive age present significant health risks, affecting maternal well-being, foetal growth, and long-term health outcomes. Gender disparities exist in the prevalence of obesity, with women generally more affected than men across Africa. Agyemang et al. (2015) observed that women are 4.5 to 8 times more likely than men to be overweight or obese, partly due to physiological factors such as greater adipose tissue accumulation (Chang et al., 2018). Hormonal contraceptives have also been linked to weight gain (Agbeko et al., 2013; Mangemba & San Sebastian, 2020). Additionally, women's roles in food

preparation and childcare increase their exposure to food, contributing to overeating (Raza et al., 2020).

Marital status is a significant predictor of overweight/obesity in women, with married women at a higher risk, possibly due to reduced physical activity and cultural perceptions linking weight gain with prosperity (Agyemang et al., 2015; Mangemba & San Sebastian, 2020). Childbearing also contributes to weight gain, as women who have given birth are more likely to be overweight or obese, especially due to postpartum practices and retained pregnancy weight (Tuoyire et al., 2016). Age is another critical factor, with older women showing higher rates of obesity, partly due to physiological changes and more sedentary lifestyles (Mangemba & San Sebastian, 2020). However, the association between age and BMI diminishes after age 60 (Agyemang et al., 2015). Education level shows mixed effects, with some studies linking higher education to increased obesity risk, while others find the opposite Tuoyire et al. (2016) Mangemba and San Sebastian (2020). Wealthier women are consistently more likely to be overweight or obese due to greater access to high-calorie foods (Lartey et al., 2019), while employment status also plays a role, with working women in sub-Saharan Africa at greater risk than non-working women (Agbeko et al., 2013). Cultural and religious factors further influence obesity risk. Christian women in Zimbabwe, for example, have a higher prevalence of obesity due to communal feasting and social practices (Mangemba & San Sebastian, 2020). In contrast, some studies find no significant link between religion and obesity (Agbeko et al., 2013).

Food insecurity is paradoxically associated with obesity, as limited access to healthy foods often leads to the consumption of cheap, calorie-dense options, promoting weight gain (Morales & Berkowitz, 2016). This is particularly evident in low-income settings where economic constraints limit dietary quality (Barosh et al., 2014). The stress of food scarcity may also

contribute to overeating when food is available (Marlow et al., 2022). Globalization has altered food markets, increasing the availability of processed, unhealthy foods in African countries, contributing to rising obesity rates in urban areas (Agyemang et al., 2015). Shifting dietary patterns in cities like Accra reflect a move away from traditional foods towards more energy-dense options (Aryee et al., 2013; Lartey et al., 2019).

In conclusion, multiple factors contribute to the higher prevalence of overweight and obesity in women, including physiological differences, reproductive factors, socio-economic status, and cultural practices. These issues are further compounded by food insecurity and globalization, making obesity a complex public health challenge that requires targeted interventions.

2.5 Anaemia in women

Anaemia is a widespread issue that affects countries worldwide (WHO, 2023a). It serves as an indicator of inadequate nutrition and poor health conditions (SWAC, 2019). The ramifications of anaemia present significant risks to the well-being of mothers, including the likelihood of miscarriages, postpartum haemorrhage, and maternal mortality (Ali et al., 2020; WHO, 2023b). Additionally, it poses risks to the well-being of newborns, resulting in stillbirths, premature births, and infants with low birth weight (Ali et al., 2020; WHO, 2023b). Importantly, the consequences of anaemia extend beyond the perinatal period, negatively impacting developmental processes, cognitive abilities, and the future potential of children (WHO, 2023b).

In the context of women of reproductive age, anaemia is characterized by a haemoglobin concentration below 120 g/l, as outlined by the World Health Organization (WHO, 2023a). The public health significance is determined by establishing thresholds, wherein a range of 5-19 percent is considered a mild public health concern, 20-39 percent is deemed a moderate concern,

and a value of 40 percent or higher is classified as a serious public health problem (WHO, 2023a). According to data from the WHO in 2020, an estimated 30% of women of reproductive age and 36.5% of pregnant women were anaemic (WHO, 2023b). Similar results were reported in the 2021 global nutrition report and other studies, which revealed that a third (30%) of women of reproductive age suffered from anaemia (GNR, 2021; Stevens et al., 2022).In 2019, the mean rates of anaemia in the Americas (15.3% [11.8–19.5%]) and Europe (18.6% [14.3–23.9%]) were below the global average according to the World Health Organization (WHO, 2023b). However, Turkey (27.8%) and Haiti (45.5%) had the highest rates of anaemia in Europe and the Americas, respectively (Mujica-Coopman et al., 2015; Saydam et al., 2017). In European countries such as Serbia, more than one in five women below the age of 50 years is anaemic (Knez et al., 2017). Conversely, Africa (39.8% [36–43.9%]) and Southeast Asia (46.5% [39.3–53.2%]) surpassed the global average (WHO, 2023b). Notable variations within Asia include India (53%–84.5%), Maldives (63%), and Pakistan (60.7%), where the prevalence exceeded the regional average (Ali et al., 2020; Sappani et al., 2023; Sunuwar et al., 2020). Sunuwar et al. (2020) reported a 6.5% increase in the prevalence of anaemia in South and Southeast Asia compared to the WHO regional estimate of 46.5 percent. Similarly, the rates of anaemia in Mali (63.5%), Benin (55%), Gabon (52%), Burkina Faso (52%), and Gambia (44.3%) were all much higher than the WHO regional average of 39.8% (Armah-Ansah, 2023; Shitu & Terefe, 2022; WBG, 2023). Zegeye et al. (2021) reported a 49.7% rate of anaemia among women in sub-Saharan Africa, compared to the 40% reported by the World Bank (WBG, 2023).

Despite global efforts, the reduction in anaemia has been uneven. While some regions have seen slight reductions, many, especially in low- and middle-income countries, have experienced either stagnation or an increased prevalence (SWAC, 2019). This is partly attributed to low dietary

diversity, as many women have inadequate intakes of crucial nutrients such as iron, folic acid, and vitamins A and B12 (GNR, 2021; WHO, 2023a). High parasitic infections among women and children (Mrimi et al., 2022; Righetti et al., 2013) and socio-economic factors also contribute to the elevated risk of anaemia among women of reproductive age (WHO, 2023a). Despite cultural resistance to interventions like micronutrient supplementation (Fite et al., 2021) , there is a growing concern regarding the health risks associated with dietary supplements (Maughan, 2013; Ronis et al., 2018). Therefore, it is crucial to identify and implement sustainable strategies within the food system to address the inadequate intake of essential micronutrients. Ethnographic foods, particularly shellfish (oyster), have been identified as rich sources of micronutrients, including minerals and vitamins (USDA, 2020a; Willer & Aldridge, 2019). Oysters also provide omega-3 polyunsaturated fatty acids, which are crucial for heart health and neurodevelopment (Shahidi & Ambigaipalan, 2018; Swanson et al., 2012). Due to their affordability and accessibility, oysters could play a significant role in reducing anaemia among women of reproductive age, particularly in coastal communities where more than 4,000 women engage in estuarine and mangrove ecosystem-based shellfishery activities, including harvesting, processing, transporting, and/or retailing of oysters (Chuku et al., 2022).

This research aims to assess the prevalence of anaemia among women involved in shell-fishing in selected communities around estuaries in Ghana. The study seeks to demonstrate the association between the coastal oyster value chain system and anaemia within the socio-ecological system of the mangrove land/seascape-shellfish. Ultimately, the findings aim to provide evidence for empowering women in shellfish livelihoods to protect mangroves and improve the nutrition of women of childbearing age.

2.5.1 Anaemia in Ghana

Over the past three decades, anaemia has consistently emerged as a prominent public health concern affecting women of reproductive age in Ghana. The 2004 demographic and health survey in Ghana reported varying prevalence rates of anaemia, ranging from 33.5% in the Brong Ahafo Region to 51% in the Upper East, with an overall average of 44.7%. The data indicated that 34.9%, 9%, and 0.8% of women of reproductive age experienced mild, moderate, and severe anaemia, respectively (GDHS, 2004). Notably, the Upper East (51%), Northern (49.8%), and Volta (49.7%) regions recorded the highest rates of anaemia, while the Brong Ahafo region exhibited the lowest prevalence at 33.5% (GDHS, 2004). Subsequent surveys conducted in 2008 revealed a 14% increase in the prevalence of anaemia, with over half of women of reproductive age now affected. Rates varied significantly, ranging from 71.2% in the Western Region to 48.4% in the Upper East (GDHS, 2008). Similarly, high prevalence was reported in the Upper West (66.9%) and Central (63.7%) regions. However, in 2014, Ghana experienced a slight reduction in anaemia prevalence among women of reproductive age. Approximately 42.4% of women were anaemic, with 32.2%, 9.8%, and 0.4% experiencing mild, moderate, and severe anaemia, respectively. Notably, the Volta region (48.7%) and the Upper West region (35.6%) exhibited the highest and lowest anaemia prevalence rates across the country (GDHS, 2014). From 2004 to 2014, the coastal regions of Ghana, including Greater Accra, Central, Western, and Volta, reported a mean prevalence of anaemia of 49.7% among women of reproductive age, according to the demographic and health survey reports. The Volta region had the highest prevalence at 51.8%, followed by the Western region with 51%, while the Central and Greater Accra regions recorded mean prevalences of 49.5% and 46.7%, respectively. The recent report indicated that 41.1% of women in Ghana were anaemic: 38.8% in the Greater Accra, 44.4% in the Central, and 45.9% in the Western Regions (GDHS,

2024). Ghose and Yaya (2018) conducted a study to examine the association between fruit and vegetable consumption and anaemia among adult non-pregnant women in Ghana. Using data from the Ghana demographic and health survey, their findings revealed that 57.9% of women were anaemic, regardless of the category. Similarly, Kushitor et al. (2020), utilizing the same dataset, estimated the prevalence of anaemia among women of reproductive age to be 41%. Beyond the demographic and health dataset, Petry et al. (2021) reported a prevalence of anaemia of 32.8% among women aged 15 to 49 years, based on nationally representative data. Another national study by Wegmüller et al. (2020) reported a significantly lower prevalence of anaemia (21.7%) among women of reproductive age. Furthermore, Christian et al. (2022), in a two-stage nationally representative survey involving 1063 women of reproductive age, identified a similar anaemia rate to that reported by Wegmüller et al. (2020).

Currently, there is significant variation in the prevalence of anaemia across studies. Differences in anaemia rates in Ghana can be attributed to geographic variation, socio-economic factors, dietary patterns, health infrastructure, parasitic infections, and lifestyle factors. Additionally, variations in anaemia prevalence among different regions in Ghana can be attributed to the use of different methodologies and data sources in these studies. For instance, Kofie et al. (2019) investigated the prevalence and associated risk factors of anaemia among postnatal women in the Volta region. Despite 1% and 5% of them experiencing parasitic infection and postpartum haemorrhage during their previous delivery, the study observed the lowest prevalence of anaemia among postnatal women at 16%. In the Upper East region, Wemakor et al. (2022) identified a relatively high prevalence of anaemia (46.7%) among postpartum women six weeks after delivery. A study conducted at Kwame Nkrumah University of Science and Technology in Kumasi revealed that almost two-thirds (67.5%) of women aged 15 to 40 years were anaemic, with prevalence rates of

mild, moderate, and severe anaemia at 35.4%, 26.7%, and 5.3% respectively (Tandoh et al., 2023). Similarly, Tay et al. (2013) found that over half (53.2%) of women of childbearing age in the same setting were anaemic. In the Greater Accra region, Agbemafle et al. (2016) discovered an overall prevalence of anaemia of 44% among women in peri-urban settlements in Accra. The prevalence of mild, moderate, and severe anaemia in the study was 35.8%, 6.7%, and 1.5%, respectively. Meanwhile, Anabire et al. (2023) explored the relationship between lifestyle factors such as alcohol and smoking, and the burden of anaemia among traders in the Tamale metropolis in the Northern region. The study found that 59.3% of female traders aged 18 years and above were anaemic. Currently, anaemia among women of reproductive age remains a moderate public health concern. According to a World Bank report, more than one-third (35%) of women aged 15 to 49 years in Ghana are anaemic (WBG, 2023). The literature review indicates that there has been extensive research conducted on anaemia among pregnant women in Ghana, with a focus on both the prevalence and predictors of anaemia, mainly within antenatal care services (Anlaakuu & Anto, 2017; Appiah et al., 2020). Additionally, studies have also been conducted on postpartum women (Kofie et al., 2019; Wemakor et al., 2022). However, there is a limited number of studies available on the prevalence of anaemia and its predictors among women of reproductive age. The majority of studies in this area rely on the Ghana demographic and health survey dataset (Ghose & Yaya, 2018; Kushitor et al., 2020; Tetteh et al., 2023), which makes it challenging to compare variations in anaemia prevalence among the general population of women due to the use of a uniform data source. In conclusion, anaemia is a widespread global health concern that affects numerous countries, particularly those with limited resources. In Ghana, the prevalence of anaemia has shown a slight decrease from 44.7% in 2008 to 42.4% in 2014. Multiple studies have revealed significant disparities in the incidence of anaemia, with reported rates ranging from as low as 16%

to as high as 67.5%. According to a GDHS report, the current estimated prevalence of anaemia among women aged 15 to 49 years is 41.1%.

2.6 Predictors of Anaemia

The prevalence of anaemia among women of reproductive age is a global health challenge influenced by various factors. This review focuses on maternal and dietary factors that impact anaemia in this demographic. The association between maternal age and anaemia has been a topic of interest in the literature. Younger age has been identified as a notable factor influencing the anaemia status of women, with characteristics commonly associated with pregnancies during adolescence contributing to the correlation between lower maternal age and anaemia (Dey et al., 2010). However, the impact of this association may vary due to factors such as geographic location, socioeconomic conditions, and healthcare infrastructure. Young women in early adulthood may still require iron for physiological functions and face challenges such as blood loss through menstruation and parasitic infections (Hamburg, 2017; Tandoh et al., 2023). Economic obstacles may also hinder young mothers from accessing nutritious meals and healthcare services, increasing their vulnerability to anaemia (Abotsi, 2020). Yasutake et al. (2013) conducted an analysis of data derived from demographic and health surveys conducted in 34 low- and middle-income countries. Their findings indicated that anaemia emerges as a noteworthy public health issue, with particular emphasis on its prevalence among adolescents and young adult women. On the other hand, advanced maternal age, generally defined as 35 years and older, has been associated with an increased risk of specific forms of anaemia (Ghosh et al., 2020) Win and Ko (2018). However, contradictory findings have been reported, with some studies finding no significant association between maternal age and anaemia (Gautam et al., 2019; Zegeye et al., 2021). In Ghana, Kofie et

al. (2019) found that younger maternal age was a protective factor against anaemia, with mothers aged 20-29 being 73% less likely to be anaemic compared to those above 40 years.

First-time pregnant women are reported to face an increased risk of anaemia due to their bodies adapting to the physiological changes of pregnancy. Insufficient iron reserves prior to pregnancy and the heightened need for nutrients, including iron, for the developing foetus contribute to this vulnerability. Conversely, physiological changes during multiple pregnancies and the postpartum period play a substantial role in blood loss, potentially leading to anaemia among women (Datta et al., 2010).

In contrast, Kofie et al. (2019) found no significant association between the number of pregnancies and anaemia among women of reproductive age in Ghana. The relationship between anaemia and parity is a significant factor in various studies. Armah-Ansah (2023) found that a parity of two was protective against anaemia among Malian women compared to those with over four births. Conversely, Teshale et al. (2020) observed that parity in general presented a significant risk of anaemia among women in Eastern Africa. Primiparity, multiparity, and grand parity all showed an elevated risk of anaemia, with rates estimated between 7% and 11% compared to nulliparity (Teshale et al., 2020). However, Kofie et al. (2019) found no significant association between parity and anaemia among women of reproductive age.

The relationship between maternal education and the likelihood of anaemia in women has also been recognized as a significant factor. Multiple studies consistently indicate the beneficial impact of maternal education in preventing anaemia (Merid et al., 2023). Women with higher education levels often have a more comprehensive understanding of the factors and outcomes associated with anaemia, leading to enhanced compliance with iron supplements, improved dietary practices, and timely antenatal care, collectively mitigating the likelihood of anaemia among

educated women (Amugsi et al., 2016; Sununtnasuk et al., 2016). Merid et al. (2023) proposed that maternal education is frequently used as a surrogate measure for socioeconomic position, with disparities in educational attainment linked to disparities in anaemia prevalence. Women with lower education levels may face difficulties related to restricted resources, limited access to healthcare services, and diminished awareness of preventive measures (Merid et al., 2023). Habyarimana et al. (2020) demonstrated a significant correlation between literacy rates and the prevalence of anaemia among women of reproductive age in Rwanda. According to Habyarimana's (2020) study, uneducated women exhibited a 1.18-fold increased risk of anaemia compared to their literate counterparts. Several other studies in Mali (Armah-Ansah, 2023), India (Ghosh et al., 2020; Sappani et al., 2023), and in LMIC (Merid et al., 2023) indicated a negative correlation between at least secondary education and anaemia among women of reproductive age. In contrast, the studies conducted by Win and Ko (2018) and Zegeye et al. (2021) did not observe a statistically significant relationship between educational attainment and the occurrence of anaemia among women in their reproductive years in Myanmar.

Numerous studies have identified variations in the prevalence of anaemia among women of reproductive age across different geographical regions. For example, Win and Ko's (2018). research on Myanmar explored geographical disparities and influencing factors associated with anaemia. The study found a twofold higher likelihood of anaemia among women in coastal zones compared to those in highland areas. Significant differences were also found among the delta, middle plain, and highland regions of Myanmar (Win & Ko, 2018). Similarly, significant variations in anaemia prevalence were observed among women in different provinces of Rwanda. Women in the Eastern and Southern provinces had a 1.5 times higher prevalence compared to those in Kigali (Habyarimana et al., 2020).

Several studies in Mali (Armah-Ansah, 2023), Gambia (Shitu & Terefe, 2022), and Ghana (Wegmüller et al., 2020) also documented geographic or rural/urban disparities in the prevalence of anaemia among women of reproductive age. Teshale et al. (2020), for example, noted a 6% lower prevalence of anaemia among women in rural areas compared to urban areas. In contrast, studies by Merid et al. (2023) and Zegeye et al. (2021) did not find a statistically significant relationship between places of residence (rural versus urban) and the occurrence of anaemia among women in their reproductive years across Low- and Middle-Income Countries (LMIC) and Sub-Saharan Africa (SSA), respectively.

Literature has linked marital status with anaemia among women, but findings vary. According to Win and Ko (2018), there is a negative association between marital status and the likelihood of anaemia, indicating that married women had a 17% lower probability of experiencing anaemia compared to unmarried women. In contrast, in Rwanda, Habyarimana et al. (2020) found that being married, at any point or currently, was associated with a 1.3- and 1.2-times higher chance of anaemia, respectively, compared to never-married women. A similar trend was observed in Eastern Africa, with married and previously married women experiencing 9% and 15% higher anaemia rates than never-married women (Teshale et al., 2020). On the other hand, studies by Kofie et al. (2019) and (Merid et al., 2023) found no significant association between marital status and anaemia among women of reproductive age. Regarding religious affiliation, Kofie et al. (2019) reported no significant prediction of anaemia in Ghana based on religious background. In Bangladesh, Kamruzzaman et al. (2015) noted significant differences in the prevalence of anaemia among ever-married, non-pregnant women, with Islamic-background women having an increased risk compared to non-Muslims. Similarly, Zegeye et al. (2021) studied 19 sub-Saharan African countries, finding that women from a Muslim background presented a significant risk of anaemia,

potentially linked to dietary restrictions influencing haemoglobin status among Muslim women in SSA.

The ethnic origin of women of reproductive age emerges as a significant predictor of anaemia in several studies (Keokenchanh et al., 2021). However, Kofie et al. (2019) and Sosa-Moreno et al. (2020) found no notable association between ethnicity and anaemia in Ghana and Ecuador, respectively. Similarly, Gautam et al. (2019) observed no significant link between ethnicity and anaemia among reproductive women in Nepal.

The current employment status of women is identified as a protective factor against anaemia. Teshale et al. (2020) discovered in Eastern Africa that women currently employed had 3% lower odds of anaemia compared to those not working. Conversely, Win and Ko (2018) and Zegeye et al. (2021) found no statistically significant association between work status and anaemia among women in the reproductive age group.

Wealth status, or quintile, is another substantial protective factor against anaemia for women. In Rwanda, Habyarimana et al. (2020) found a reduced likelihood of anaemia among women in higher wealth quintiles. Women from poor households exhibited a 1.4-fold higher likelihood of anaemia compared to those from affluent households, with no significant association found for the middle quintile Habyarimana et al. (2020). Armah-Ansah (2023) observed in Mali that women from the highest quintile were at reduced risk of anaemia compared to those from the lowest quintile. Across 24 LMICs and 19 SSA countries, the odds of anaemia decreased with increasing wealth status (Merid et al., 2023; Zegeye et al., 2021). Similar findings were reported in Ghana and India, where women from poor households had an increased risk of anaemia (Sappani et al., 2023; Wegmüller et al., 2020). In Eastern Africa, a 6–11% reduction in anaemia risk was estimated for women in the second to highest quintiles compared to those in the lowest quintile (Teshale et

al., 2020). In contrast, Win and Ko (2018), Gautam et al. (2019), and Wilunda et al. (2013) found no statistically significant correlation between wealth level and anaemia in women of reproductive age. Household size is a risk factor for anaemia in women of reproductive age. In Rwanda, increasing household size by one individual increased the likelihood of anaemia by 5% (Habyarimana et al., 2020). Similarly, Merid et al. (2023) found that a family size of ten or more increased the odds of anaemia by 1.2 in low- and middle-income countries. Another study in Eastern Africa showed that larger household sizes were associated with a higher rate of anaemia, with a household size of six linked to a 5% increase in anaemia (Teshale et al., 2020).

The choice of fuel for domestic use is an important factor in anaemia occurrence in women. Ford et al. (2022) found a connection between cough (indicating exposure to smoke from burning biomass for cooking fuel) and anaemia in women. The fine particulate matter in the smoke can enter the respiratory system, bloodstream, and disrupt the capacity of red blood cells to carry oxygen, leading to reduced oxygen transport, tissue hypoxia, and anaemia (Armo-Annor et al., 2021). However, cough in this study may also indicate other respiratory conditions.

Smoke emission from burning biomass fuel has been linked to a higher risk of mild anaemia (1.38) and moderate-to-severe anaemia during pregnancy (1.79) compared to using clean fuel in Nagpur, India Page et al. (2015). He et al. (2022) observed that the impact of cooking fuel on anaemia risk was only seen among women with low socioeconomic status. On the other hand, the use of charcoal and straw/grass/shrub materials was not found to be a significant predictor of anaemia among women in Rwanda (Habyarimana et al., 2020), Tanzania (Wilunda et al., 2013), and Sri Lanka (Pathirathna et al., 2022). Armo-Annor et al. (2021) did not find a significant association between using biomass fuel for cooking and the prevalence of anaemia among women. However, they did find that women engaged in fish smoking had a higher prevalence of anaemia

(6%) and an 80% greater risk of developing anaemia compared to women in other livelihoods, possibly due to their exposure to external smoke from fish smoking activities (Armo-Annor et al., 2021).Maternal interventions such as mineral supplementation and anaemia prevention strategies, including the use of treated bed nets, have yielded conflicting results in the battle against anaemia. Kofie et al. (2019) reported that neither bed net usage nor iron-folic supplements significantly reduced anaemia among Ghanaian women of reproductive age. Conversely, higher dietary nutrient intake in Saudi Arabia positively predicted the anaemia status of women (AlFaris et al., 2021)

In a similar vein, Jones et al. (2017) found an association between anaemia in women of reproductive age and household food insecurity in Mexico. The study revealed that women residing in households with moderate food insecurity had a 33% higher likelihood of experiencing anaemia, while those in highly food-insecure households had a 36% higher likelihood.

Access to a diverse range of food sources emerges as a protective factor against anaemia for women, as both plant and animal-based foods provide essential haem and non-haem sources of protein crucial for building iron stores. Numerous studies have emphasized the significant impact of dietary diversity on the anaemia status of women of reproductive age. For example, Jin et al. (2022) found that consuming a diet consisting of more than five different food groups was associated with a 30% reduction in the likelihood of mild anaemia in India. However, no statistically significant relationships were observed between dietary diversity and the occurrence of moderate or severe anaemia. Ghosh et al. (2020) noted that women who did not achieve the minimum dietary diversity were 1.6 and 18.2 times more likely to have moderate and severe anaemia in West Bengal, India. The study attributed the risk to inadequate intake of iron-rich foods. In contrast, Tandoh et al. (2023) found no significant association between dietary diversity and anaemia among Ghanaian women in Kumasi.

The prevalence of anaemia was higher among women classified as underweight compared to those with a normal or above-normal body mass index (BMI). In a study by Petry et al. (2021) in Ghana, overweight or obese women were found to have decreased risks of anaemia. Similarly, Armah-Ansah (2023), Gautam et al. (2019), and Merid et al. (2023) observed a negative association between overweight/obesity and anaemia among women in Mali, Nepal, and LMIC, respectively, except in Ethiopia (Woldu et al., 2020). Win and Ko (2018) discovered that women with a normal BMI had a 15% reduced likelihood of anaemia compared to underweight women. In Rwanda, Habyarimana et al. (2020) found a significantly higher prevalence of anaemia in underweight women compared to those of normal weight, while being overweight or obese was protective against anaemia among Malian women. Merid et al. (2023) also highlighted the significant association between underweight and anaemia among women. However, Petry et al. (2021) and Tandoh et al. (2023) found no significant association between maternal underweight and anaemia among women.

A noteworthy risk factor for anaemia in women is breastfeeding, as revealed by a multinational study conducted by Merid et al. (2023). The odds of anaemia among non-breastfeeding women decreased by 14% compared to their counterparts, possibly due to nutrient deficiencies and the additional nutritional demands associated with breastfeeding. In contrast, Gautam et al. (2019) found no significant association between breastfeeding and anaemia among women in Nepal.

In summary, addressing anaemia in women requires understanding factors such as age, parity, education, geographical location, BMI, employment, wealth status, household size, and fuel sources. Access to diverse food sources is protective, while interventions like bed nets and mineral supplementation yield conflicting results. Religious affiliation and ethnic origins contribute to

disparities, and breastfeeding emerges as a potential risk factor. An effective approach to anaemia prevention and intervention requires nuanced strategies that consider these influences.

2.7 Dietary energy and micronutrients (iron and Zn) intakes of women of reproductive age

Adequate dietary energy intake is essential for women of reproductive age, as it directly influences their physical and mental well-being. Insufficient energy intake can lead to malnutrition, menstrual irregularities, reduced fertility, and increased risks during pregnancy and breastfeeding, as the body requires additional energy to support foetal growth and milk production (Marshall et al., 2022; Silvestris et al., 2019). The recommended daily energy intake for adult women is approximately 2,000 calories, serving as a baseline for maintaining health and activity (NASEM et al., 2017). Globally, many women continue to experience inadequate dietary energy intake despite improvements in food availability. For instance, in the United States, the average daily energy intake for women aged 18-39 ranges from 1,844 to 1,957 kcal/day, depending on ethnicity (Ladabaum et al., 2014). In Vietnam, women consume higher calories, averaging 2,196 kcal/day, which aligns with dietary recommendations (Nguyen et al., 2013). However, in rural India, women's energy intake is significantly lower, ranging from 983.6 to 1,434.7 kcal/day, far below international recommendations (Mittal, 2013; Sharma et al., 2020). Disparities in energy intake are similarly observed across African countries. In Ethiopia, women consumed an average of 2,682.7 kcal/day, exceeding the recommended allowance by 34% (Bekele et al., 2023). Conversely, in Nigeria, women's energy intake averaged 2,094.83 kcal/day (Orewa & Iyanbe, 2010). In Ghana, dietary energy intake varies significantly by region, with women in urban areas consuming between 2,265 and 2,626 kcal/day, while rural women consumed less, averaging between 1,735 and 1,926 kcal/day (Appiah et al., 2014; Kobati et al., 2012). Research in Ghana

also indicates that urban women tend to consume more calories than the global recommendations, with an average intake of 2,475 kcal/day (Galbete et al., 2017). The variations in energy intake can be attributed to factors such as geographic location, socioeconomic status, and food availability. Although food availability has increased in many regions, inadequate dietary intake persists among vulnerable populations, leading to adverse health outcomes for women.

Iron and zinc are crucial minerals for women's health, particularly during their reproductive years. Iron plays a key role in haemoglobin production, which transports oxygen in the bloodstream, and is essential for neurological development and metabolic processes (Shaffer & Thomas, 2023). Zinc is critical for cellular metabolism, immune function, and reproductive health (Shaffer & Thomas, 2023). Deficiencies in these minerals can lead to anaemia, weakened immunity, and other health complications (Samson et al., 2022; Wessells & Brown, 2012). The recommended dietary allowance (RDA) for iron is 18 mg/day for women aged 15-50 and 27 mg/day for pregnant women due to increased blood volume and foetal needs (NIH, 2023). For zinc, the RDA is 8 mg/day for adult women, 11 mg/day during pregnancy, and 12 mg/day while breastfeeding (NIH, 2022b). Despite these recommendations, many women globally fall short of these requirements, which poses significant health risks. Studies reveal varying iron intake among women across different regions. A systematic review by Milman (2019) found that women in Europe generally consumed less than their recommended intake of 15 mg/day of iron, with 61-97% of women in countries like Belgium, Denmark, and Sweden having suboptimal iron intake. Similar trends were observed in Serbia, where 96.6% of women failed to meet the recommended iron intake. The study found average intake of iron to be 9.4 mg/day (Knez et al., 2017). Then again, in Australia, one-third of women had inadequate intake, averaging 10.5 mg/day (Lim et al., 2015). In developing countries, iron intake is often even lower. In India, for example, urban women

in slums consumed around 7.2 mg/day, far below the recommended levels (Nunn et al., 2019). Similarly, women in Bangladesh had a mean intake of 11.6 mg/day, which, although higher, still fell short of the 18 mg/day requirement (Wable Grandner et al., 2021). In Africa, iron intake varies widely. Harika et al. (2017) found that iron consumption ranged from 3.8 mg to 97.8 mg/day across countries like Nigeria, Ethiopia, and South Africa, with significant proportions of women not meeting the RDA. In Ghana, women's iron intake was relatively higher, with coastal women consuming 23.2 mg/day and those in the Guinea zone consuming 28.7 mg/day Kobati et al. (2012), indicating adequate intake among certain populations. Similar findings were reported in peri-urban areas where women consumed around 24 mg/day (Agbemafle et al., 2016).

Zinc is vital for numerous bodily functions, but like iron, many women do not consume enough. Studies have found zinc intake to be below the RDA in various regions. In Serbia, women consumed an average of 7.3 mg/day, with many falling short of the RDA(Knez et al., 2017). In Australia, women's intake averaged 9.3 mg/day, but 19% had insufficient zinc intake (Lim et al., 2015). In India, zinc intake was even lower, ranging from 5.1 to 5.5 mg/day among various cohorts of women (Sharma et al., 2020). Similarly, women in Indian rural and tribal areas consumed as little as 5.3 mg/day (Herbst et al., 2014). In sub-Saharan Africa, zinc intake varies considerably. Harika et al. (2017) found that zinc consumption ranged from 3.8 to 16.2 mg/day, with a large proportion of women in countries like Nigeria, Ethiopia, and South Africa having inadequate intake. In Zambia, women consumed an average of 7.82 mg/day, but a third of them had zinc intake below the estimated average requirement (Kaliwile et al., 2019). In Ghana, women's zinc intake ranged from 7.6 to 8.9 mg/day, with 38.9% to 44.4% of women falling below the recommended levels (Kobati et al., 2012).

The dietary intakes of iron and zinc among women of reproductive age vary significantly across different countries and regions. While some populations meet or exceed the recommended levels, a substantial proportion of women, particularly in developing countries, consume inadequate amounts of these essential minerals. This inadequate intake can lead to adverse health outcomes, highlighting the need for targeted interventions to address deficiencies and ensure optimal health for women during their reproductive years.

2.8 Consumption of oysters

Oysters, which are edible bivalve molluscs belonging to the Ostreidae family, inhabit marine and brackish environments, including mangrove ecosystems. They serve as a crucial source of protein, particularly for coastal communities (Osei et al., 2021a). Noteworthy species comprise the European flat oyster, Pacific oyster, Eastern oyster, Olympia oyster, and Sydney rock oyster, each exhibiting variations in appearance contingent upon their respective habitats (Yu et al., 2023). The consumption of oysters is influenced by geographic and regulatory factors. In Denmark, oysters are classified as state property, necessitating permits for commercial harvesting, whereas in Sweden and Norway, landowners exercise control over the oysters located near the shoreline (Mortensen et al., 2019). France holds the distinction of being the leading producer and exporter of oysters, while the United States is prominent in terms of imports and consumption (OEC, 2024; Prod'homme, 2023). Despite these substantial quantities, per capita consumption remains relatively modest, with figures of 1.07 g/day in the United States and 5.5 g/day in France (García-Rico & Tejeda-Valenzuela, 2020). In contrast, oyster consumption in Asia is considerably higher, with daily intakes reported at 18.6 – 56.0 g in Taiwan, 28.7 – 29.0 g in China, and 19.8 g in Korea (Gong et al., 2020; Liu et al., 2006; Liu, 2018; Mok et al., 2015). Brazil also notes a consumption

rate of 35.7 g/day (Vieira et al., 2021). In Mexico, consumption patterns differ across age groups, with adults averaging 14.3 g/day and children consuming up to 42.9 g/day (Aguilar et al., 2021). Oysters may be consumed raw, cooked, or as a condiment and are essential for food security in regions such as Ghana (Osei et al., 2021a). The geographic origin of oysters is frequently highlighted in marketing strategies, particularly in France and the United States, due to their unique qualities (Mortensen et al., 2019). In summary, oysters represent a significant global food source, with consumption patterns exhibiting considerable variation across different regions, driven by cultural preferences, regulatory frameworks, and availability.

2.8.1 Micromineral concentrations in oysters

Oysters are renowned for their high concentrations of essential vitamins and minerals, though their nutritional composition can vary depending on factors such as location, season, and farming practices (Soetan et al., 2010; USDA, 2020a). Oysters are a significant source of microminerals, including iron, manganese, copper, zinc, selenium, chromium, and cobalt, all of which play critical roles in human health (Miller, 2017). Iron concentrations in oysters vary by species and region. In Brazil, Crassostrea Gasar species were found to contain iron levels as high as 522 mg/kg, significantly higher than other species (Santos & Boehs, 2021). Studies in India and China reported lower concentrations of 32-43 mg/kg and 5.6-13.1 mg/kg, respectively, with geographical and species differences being primary factors (Chakraborty et al., 2016; Zhu et al., 2018b). African studies have recorded higher iron concentrations, particularly in Ghana and Congo, ranging from 400 mg/kg to 924 mg/kg (Ampofo-Yeboah, 2014; Suami et al., 2019). Manganese is essential for bone formation and wound healing. In Brazil, oysters contained manganese levels ranging from 15.3 to 26.1 mg/kg, while African studies found concentrations between 17.5 and 55.0 mg/kg

(Santos & Boehs, 2021; Tuo et al., 2020). However, in India, manganese levels were found to be relatively lower (Chakraborty et al., 2016). Copper, vital for enzymatic reactions, is abundant in oysters. In Brazil, Crassostrea Gasar had a copper concentration of 60.2 mg/kg, while studies from Mexico, the USA, and Africa report varying copper levels, ranging from 7.7 to 259.0 mg/kg (García-Rico & Tejeda-Valenzuela, 2020; Góngora-Gómez et al., 2017). Oysters from Ghana exhibited 70 mg/kg of copper Abreu et al. (2020). Oysters are an exceptionally rich source of zinc. Studies in Brazil found zinc levels exceeding 2,600 mg/kg, the highest among all sampled foods Santos and Boehs (2021). Zinc concentrations vary worldwide, with lower levels observed in countries such as India (33-44 mg/kg) and Indonesia (3.7-11.5 mg/kg) (Chakraborty et al., 2016). Selenium is known for its antioxidant properties. Selenium levels in oysters vary, with reports ranging from 0.18 to 3.54 mg/kg in Congo and 2.3 mg/kg in Ghana (Abreu et al., 2020; Suami et al., 2019). In India, selenium concentrations in oysters were found to be 0.1 to 0.5 mg/kg (Chakraborty et al., 2016). Chromium, essential for insulin regulation, is present in oysters at varying levels. Brazilian oysters contained chromium levels around 3.3 mg/kg, while studies in the USA, Mexico, and Japan reported lower concentrations ranging from 0.3 to 25.0mg/kg (Góngora-Gómez et al., 2017; Santos & Boehs, 2021). Cobalt, essential for vitamin B12 production, is found in oysters, with concentrations ranging from 1.91 mg/kg in Congo to 90 mg/kg in Ghana (Abreu et al., 2020; Suami et al., 2019). These variations may result from species differences and environmental factors. Micromineral concentrations in oysters vary widely across species and regions, influenced by environmental and biological factors. Oysters serve as an important dietary source of essential minerals, contributing significantly to human nutrition globally.

2.8.2 Macromineral concentrations in oysters

Oysters are a significant source of essential macrominerals, which are required in quantities exceeding 100 milligrams per day. The concentrations of these macrominerals exhibit considerable variation depending on species, geographical region, and environmental factors (Soetan et al., 2010; USDA, 2020a). Calcium (Ca) is crucial for the structural integrity of bones and teeth, as well as for cellular signalling processes. The calcium content in oysters displays substantial variability across different regions. In India, wild oysters have been reported to contain calcium levels ranging from 1588 to 1747 mg/kg, while cultured varieties exhibit lower concentrations of 1186 to 1235 mg/kg (Chakraborty et al., 2016). In China, Crassostrea gigas oysters have been found to possess calcium concentrations of up to 5160 mg/kg (Zhu et al., 2018b). Moreover, in Ghana, the Ca content in oysters from the Northern zone reached as high as 11444 mg/kg (Ampofo-Yeboah, 2014). Phosphorus (P) is indispensable for energy metabolism and the maintenance of bone structure. In wild oysters, phosphorus concentrations range from 3106 to 3284 mg/kg, whereas cultured samples tend to have higher P levels, between 5184 and 5302 mg/kg (Chakraborty et al., 2016). Notably, mangrove oysters in Ghana demonstrated P concentrations of 8810 mg/kg (Abreu et al., 2020). Magnesium (Mg) is essential for energy production and various cellular functions. Oysters sourced from Japan were reported to contain Mg levels of 650 to 750 mg/kg, with some Chinese oysters exhibiting concentrations as high as 3710 mg/kg (Yoda et al., 2021; Zhu et al., 2018b). In Ghana, mangrove oysters have been found to contain 5310 mg/kg of Mg (Abreu et al., 2020). Sodium (Na) plays a vital role in maintaining cellular fluid balance and regulating blood pressure. The Na content in oysters varies significantly, with Indian oysters showing concentrations between 1354 and 1964 mg/kg (Chakraborty et al., 2016) and Japanese oysters ranging from 5100 to 5500 mg/kg (Yoda et al., 2021). Potassium (K) is necessary for

muscle function and nerve transmission. Indian oysters exhibited potassium content of 2654 to 2720 mg/kg in wild samples and 5046 to 5154 mg/kg in cultured samples (Chakraborty et al., 2016). In Japan, K concentrations ranged from 1800 to 2500 mg/kg (Yoda et al., 2021), while Ghanaian oysters contained 255 mg/kg (Abreu et al., 2020). The macromineral content of oysters varies markedly based on species and location. These minerals, including Ca, P, Mg, Na, and K are integral to human health and contribute significantly to the dietary value of oysters.

2.8.3 Heavy metal concentrations in oysters

Heavy metals are naturally present in the environment; however, they can also infiltrate food sources due to human activities, including industrial processes, agriculture, and waste disposal. Oysters, which consume marine algae, are known to accumulate heavy metals at concentrations significantly higher than those found in the surrounding water (Kato et al., 2020; Witkowska et al., 2021). The accumulation of heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) in oysters raises public health concerns due to their potential toxicity. Cadmium concentrations in oysters exhibit regional variation. Elevated Cd levels have been identified in Mexican oysters (3.46 mg/kg) and oysters from the United States (1.35–1.51 mg/kg), both of which exceed the European Union limit for mussels García-Rico and Tejeda-Valenzuela (2020) (Góngora-Gómez et al., 2017). In contrast, lower levels have been reported in oysters from China (0.11–0.92 mg/kg) and the Philippines (0.03–0.33 mg/kg) (Gong et al., 2020; Valencia et al., 2021). In Africa, Cd concentrations ranged from 0.03 to 0.31 mg/kg in the Congo (Suami et al., 2019) and 0.26 mg/kg in Ghana (Abreu et al., 2020), with exceptionally high levels reported in Southern Togo (16.42–62.6 mg/kg) (Solitoke et al., 2021). Lead concentrations in oysters also demonstrate considerable variability. Brazilian oysters displayed high Pb levels (149.18 mg/kg) attributed to nautical activities (Santos & Boehs, 2021). In the USA, Pb concentrations ranged

from 0.28 to 0.83 mg/kg (Buck et al., 2024). Similarly, Mexican oysters contained Pb levels between 0.25 and 0.55 mg/kg (Góngora-Gómez et al., 2017). African studies reported lower concentrations, with Congo oysters containing 0.34 mg/kg (Suami et al., 2019) and Ghanaian samples showing 0.42 mg/kg (Abreu et al., 2020). Elevated levels were observed in Côte d'Ivoire (up to 75.48 mg/kg) and Southern Togo (up to 21.08 mg/kg) (Solitoke et al., 2021; Tuo et al., 2020). Mercury levels in oysters generally remain within regulatory limits. Oysters from the USA contained Hg concentrations of 0.04–0.095 mg/kg (Buck et al., 2024), while Mexican samples ranged from 0.018 to 0.066 mg/kg (Frías-Espericueta et al., 2018). In China and Korea, Hg levels were below permissible limits, with concentrations ranging from 0.001 to 0.008 mg/kg and 0.0023 mg/kg, respectively (Gong et al., 2020; Mok et al., 2015). African studies reported lower Hg concentrations, with Togo exhibiting levels of 0.05–0.473 mg/kg (Solitoke et al., 2021). Arsenic concentrations in oysters are also concerning. Brazilian oysters exhibited As levels above the EU limit (0.805 mg/kg) (Santos & Boehs, 2021). Oysters from the USA and China showed relatively lower levels (0.07 mg/kg and 0.23 mg/kg, respectively) (García-Rico & Tejeda-Valenzuela, 2020; Gong et al., 2020). However, Japanese oysters had exceptionally high As levels (180–228 mg/kg) attributed to the use of antifouling paints in aquaculture (Han et al., 2020). In Africa, arsenic levels ranged from 0.11 to 1.34 mg/kg in Southern Togo and 0.06 mg/kg in Ghana (Abreu et al., 2020; Solitoke et al., 2021). Overall, heavy metal contamination in oysters varies widely across different regions and species, with cadmium, lead, mercury, and arsenic levels presenting potential risks to human health. While the majority of studies report levels within permissible limits, certain regions, particularly in Africa and parts of Asia, display elevated concentrations that exceed safety standards, underscoring the necessity for global regulation and monitoring.

2.8.4 Public Health Concerns Associated with Oyster Intake

The consumption of shellfish can present public health concerns due to the potential contamination with harmful bacteria, viruses, and toxins. Noroviruses (NoV) are a major cause of foodborne illness from oysters, with outbreaks in Japan leading to a temporary decline in demand (Sakai et al., 2019). NoV can survive the 24-hour depuration process, remaining in both treated and untreated oysters, raising safety concerns (Battistini et al., 2021; Sunday & Ofonmbuk, 2020). However, thorough cooking can inactivate NoV and reduce infection risks. In contrast, toxins from harmful algal blooms, which cause illnesses like paralytic shellfish poisoning, cannot be eliminated by cooking, posing significant health risks (Battistini et al., 2021; Sunday & Ofonmbuk, 2020). Preventive measures, including routine surveillance of shellfish harvesting areas, proper handling, and public awareness, are essential to mitigate microbial contamination and protect consumers (Sakai et al., 2019).

2.8.5 Regulatory limits and estimated daily intakes from oyster consumption

Oyster consumption can result in the ingestion of heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As), which present potential health risks. Various regulatory agencies, including the Food and Agriculture Organization (FAO), the European Food Safety Authority (EFSA), and the World Health Organization (WHO), have established permissible limits for these metals in food. Specifically, the allowable limits for bivalves are 1.0–2.0 mg/kg for Pb, 1.0–2.0 mg/kg for Cd, 0.5–1.0 mg/kg for Hg, and 0.09 mg/kg for inorganic As (EFSA, 2006). The estimated daily intake (EDI) of Cd from oysters varies by region. In China, the EDI of Cd has reached levels as high as 1008 µg/kg, which exceeds established safety limits (Luo et al., 2018). In contrast, studies conducted in Korea and the Philippines have reported lower EDIs, remaining

well below regulatory thresholds (Mok et al., 2015; Montojo et al., 2021). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) of 4 µg/kg for Hg. The EDI of Hg from oysters is generally low, with reported values of 0.0043–0.005 µg/kg in China and 0.000045 µg/kg in Korea, all of which are below regulatory limits (Gong et al., 2020; Mok et al., 2015). Lead intake from oysters exhibits regional variations. In Japan, Pb intake has been reported at higher levels (3.22–5.7 µg/kg), whereas China and the Philippines have recorded significantly lower levels, all remaining below regulatory limits (Han et al., 2020; Montojo et al., 2021). For inorganic arsenic, the FAO/WHO has established a tolerable daily intake (TDI) of 2.1 µg/kg. EDI of arsenic from oysters is relatively low in China (0.0114 µg/kg) and Korea (0.05 µg/kg), but is significantly elevated in Japan (100–112 µg/kg) (Han et al., 2020). Heavy metal intake from oyster consumption varies by region, with the majority of EDIs remaining below established safety limits, indicating a generally low risk to human health. Nevertheless, elevated levels of Cd and Pb reported in certain regions, particularly in Japan and China, raise concerns and underscore the necessity for stringent environmental regulations.

2.8.6 Adverse non-carcinogenic health effects associated with oyster consumption

Oyster consumption poses potential risks associated with heavy metal contamination, specifically lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As). Nevertheless, the majority of studies indicate no significant non-carcinogenic health effects. Most research reports low non-carcinogenic risks stemming from Pb contamination in oysters. The Environmental Protection Agency's National-scale Air Toxics Assessment (NATA) employs the Target Hazard Quotient (THQ) for the assessment of toxic risks. The THQ is defined as "the ratio of the potential exposure to a substance and the level at which no adverse effects are expected (calculated as the exposure

divided by the appropriate chronic or acute value)" (Goumenou & Tsatsakis, 2019). Furthermore, the cumulative sum of hazard quotients for toxic substances impacting the same target organ or organ system is referred to as the Hazard Index (HI). This indicates that different toxic substances present within a given matrix can induce similar adverse health effects when combined with other toxins. This methodology has been adopted to estimate the risks associated with the consumption of food substances, such as oysters contaminated with heavy metals (Buck et al., 2024; Gong et al., 2020; Mok et al., 2015). Several studies have used these indicators to determine potential adverse health risk with the consumption of oysters. For example, in countries such as the Philippines, China, and Korea, target hazard quotient (THQ) values for Pb were below 1, which suggests no potential health risk (Gong et al., 2020; Mok et al., 2015; Valencia et al., 2021). Similarly, even in Boston Harbour, USA, Pb contamination was found to pose minimal risk (Buck et al., 2024). The THQ for Cd in oysters is generally low, indicating no significant health risks in countries like the Philippines, China, and Korea (Gong et al., 2020; Mok et al., 2015; Valencia et al., 2021). However, oysters sourced from the Mariculture Zone in China exceeded a hazard quotient (HQ) of 1, suggesting potential health risks (Luo et al., 2018). Several studies, including those conducted in Mexico and the USA, reported low THQs for Hg, indicating minimal risk associated with oyster consumption (Nguyen, 2019). These findings are consistent with those from Korea and the United States, where Hg intake from oysters posed no significant health threat (Buck et al., 2024; Mok et al., 2015). Most studies indicate no significant non-carcinogenic risk from arsenic exposure, with the exception of isolated cases in Brazil and Malaysia, where elevated As levels posed potential risks (Affizah et al., 2009; Vieira et al., 2021). However, studies from China, Korea, and the United States reported safe As levels in oysters (Buck et al., 2024; Gong et al., 2020; Mok et al., 2015). The overall Hazard Index (HI) for non-carcinogenic risks from heavy

metals in oysters remains below 1 in the majority of studies, indicating a low risk. Nonetheless, some isolated studies, such as those conducted in Boston Harbour, reported an elevated HI, suggesting potential health concerns when considering the cumulative effects of multiple heavy metals (Buck et al., 2024). In summary, oyster consumption presents minimal non-carcinogenic health risks related to heavy metals such as Pb, Cd, Hg, and As, according to most studies. However, isolated cases, particularly in regions with high pollution levels, underscore the need for ongoing monitoring and regulation to mitigate potential risks.

2.8.7 Adverse carcinogenic health effects associated with oyster consumption

The consumption of oysters contaminated with toxic metals such as cadmium (Cd), lead (Pb), and arsenic (As) presents considerable carcinogenic health risks. These metals, which enter the food chain through both natural processes and anthropogenic activities, disrupt cellular functions, damage DNA, and contribute to long-term health consequences, including cancer (Kato et al., 2020; Witkowska et al., 2021). Exposure to Cd from oyster consumption has been associated with carcinogenic effects. Research conducted in China indicated that Cd contamination in oysters (C. ariakensis) presented an unacceptable cancer risk across all age groups, with lifetime cancer risks for adults, adolescents, and children ranging from 2.82×10^{-3} to 3.76×10^{-3} (Gong et al., 2020; Luo et al., 2018). Conversely, assessments in the Philippines indicated that the Cd-related cancer risk arising from oyster consumption remained within acceptable limits (Montojo et al., 2021). Variations in oyster consumption rates and Cd content across different regions contribute to these divergent findings. Pb is a well-documented carcinogen, with chronic exposure associated with cancer development. Nevertheless, studies have reported low cancer risks resulting from Pb exposure through oyster consumption. In China, the estimated cancer risk was found to be

negligible (8.65×10^{-7}) in comparison to acceptable thresholds (Gong et al., 2020). Similarly, Japanese women who consumed oysters exhibited a very low probability of cancer, with estimates ranging from 2.74×10^{-8} to 4.84×10^{-8} (Han et al., 2020). Arsenic is acknowledged as a toxic and carcinogenic agent. In Japan, As contamination in oysters was linked to a significant cancer risk (1.50×10^{-4} to 1.68×10^{-4}) for women consuming 18.6 to 56 g/day of oysters (Han et al., 2020). In contrast, studies conducted in China and the United States reported lower cancer risks associated with As exposure, with a mean cancer risk of 1.75×10^{-5} in China (Gong et al., 2020) and similar findings in the United States (García-Rico & Tejeda-Valenzuela, 2020). Disparities in estimates of inorganic As levels and daily consumption patterns contribute to these contrasting results. Oyster consumption, particularly in regions with elevated contamination levels of Cd, Pb, and As, may augment the risk of cancer. In summary, the review observed significant variations in the carcinogenic risk of oyster consumption. While studies from China and Japan indicate significant carcinogenic risks, evidence from the Philippines and the United States suggest that cancer risks remain within acceptable thresholds. Variations in metal content, daily consumption, and risk assessment methodologies highlight the necessity for consistent monitoring and regulation to mitigate these health risks.

PART TWO: OBJECTIVES AND METHODS

CHAPTER 3: Study Objectives

3.1 Aim

The main aim of the study was to assess the food insecurity and nutritional status of women shellfishers, as well as the potential role of oysters as a source of dietary minerals in three estuarine sites in Ghana.

3.2 The specific objectives were:

1. To examine differences in the prevalence of food insecurity and identify key factors influencing it among women shellfishers of reproductive age across three estuarine sites in Ghana.
2. To assess differences in anaemia and overweight/ obesity status among women shellfishers and explore their relationships with maternal dietary and socioeconomic characteristics.
3. To evaluate variations in dietary mineral concentrations of oysters across estuarine sites and assess potential health risks associated with their consumption.
4. To examine dietary intake patterns of calories, iron, and zinc among women of reproductive age and estimate the contribution of oysters to total dietary mineral intake

CHAPTER 4: Methods

4.1 Study design, setting, and participants

This was a cross-sectional study, and data were collected between June and July 2021. The study was conducted at three estuarine sites: Densu, Narkwa Lagoon, and Whin estuary, situated in the Greater Accra, Central, and Western regions of Ghana, respectively (**Figure 4.1**). These sites were purposively selected based on their ecological health and the involvement of women in shellfish harvesting activities. The Densu estuary was characterised by significant ecological degradation (Chuku et al., 2020). Bortianor neighbourhood within the Densu estuarine site is further subdivided into the Bortianor, Tettegu, and Tsokomey suburbs. The estuarine site encompasses an estimated land area of about 5,892 hectares and was designated as a Ramsar site in 1992 to preserve its wetland ecosystem (Janha et al., 2017a). The Bortianor neighbourhood is a diverse community comprising various ethnic groups, primarily the Gas and other migratory groups like the Ewes (Danso, 2013; Janha et al., 2017a), and has a total population of 34,453 (GSS, 2014c). Fishing is the primary occupation of the residents in the Bortianor neighbourhood. The estimated seasonal yield of mangrove oysters from the Densu estuary is 8,816 kg per person (Osei et al., 2021b). Additionally, families engage in vegetable farming and cultivate staples such as cassava (Danso, 2013). The Densu estuarine site is the only location where the harvesting of oysters is strictly regulated due to ongoing aquaculture experiments aimed at boosting the oyster population (Osei et al., 2021b).

In contrast, Narkwa Lagoon was classified as moderately healthy, while the Whin estuary was deemed healthier, marked by dense mangrove vegetation that provides robust ecosystem services (Osei et al., 2021b). Narkwa Lagoon was the second study site, located in the Central region of Ghana. The lagoon almost surrounds the Narkwa community in the southern part, from which it

derives its name. It covers an area of 110 hectares and consists of mangrove vegetation and an estuarine site (Chuku et al., 2020). The primary economic activity in the community is artisanal marine fishing. Women residents in the southeastern part of Narkwa depend solely on shellfish trade (harvesting, processing, and sale) for their livelihoods, while others are engaged in farming (Chuku et al., 2020). The estimated annual yield of mangrove oysters from the lagoon is 9,512 kg per person (Osei et al., 2021b). The Whin estuary, located in the Ahanta West District of the Western region, is the third study site. Several communities, including Adakope, Apremdo, Beach Road, Beahu, Kokompe, and New Amanful, depend on the Whin estuary for their livelihoods. The communities enlisted in the Whin estuary were Apremdo, Beahu, and New Amanful, with a combined population of 20,009 (GSS, 2014a, 2014b). Unlike the Narkwa and Densu estuaries, the Whin estuary benefits from dense and healthy vegetation, providing protection (Chuku et al., 2020). The Whin estuary's estimated seasonal yield of mangrove oysters is 6,960 kg per person (Osei et al., 2021b). Unlike the other estuaries, the Whin estuary supports year-round oyster harvesting and is a popular tourist destination. In addition to shell-fishing, women in this area are involved in farming and trading as secondary occupations, particularly during the season of heavy torrential rains (Duguma et al., 2022).

The study communities were selected purposefully due to the active involvement of women in shell fishing activities. The study participants were women shellfishers aged 15 to 49 years, residing in the communities adjacent to the three estuarine sites. Eligible participants were actively involved in oyster value chain, including harvesting, processing, and retailing, and who had resided in the study area for a minimum of six months prior to the data collection period. However, women who declined to provide informed consent or reported pregnancy at the time of recruitment were excluded from the study.

The Ghana Health Service granted ethics approval (GHS-ERC 015/12/20) for the study. Informed consent was obtained from all participants. Permission was also obtained from local authorities, including community chiefs, assembly members, and other opinion leaders, before data collection. Public health safety measures were implemented to protect study participants and staff, including the provision of personal protective equipment during the COVID-19 pandemic.

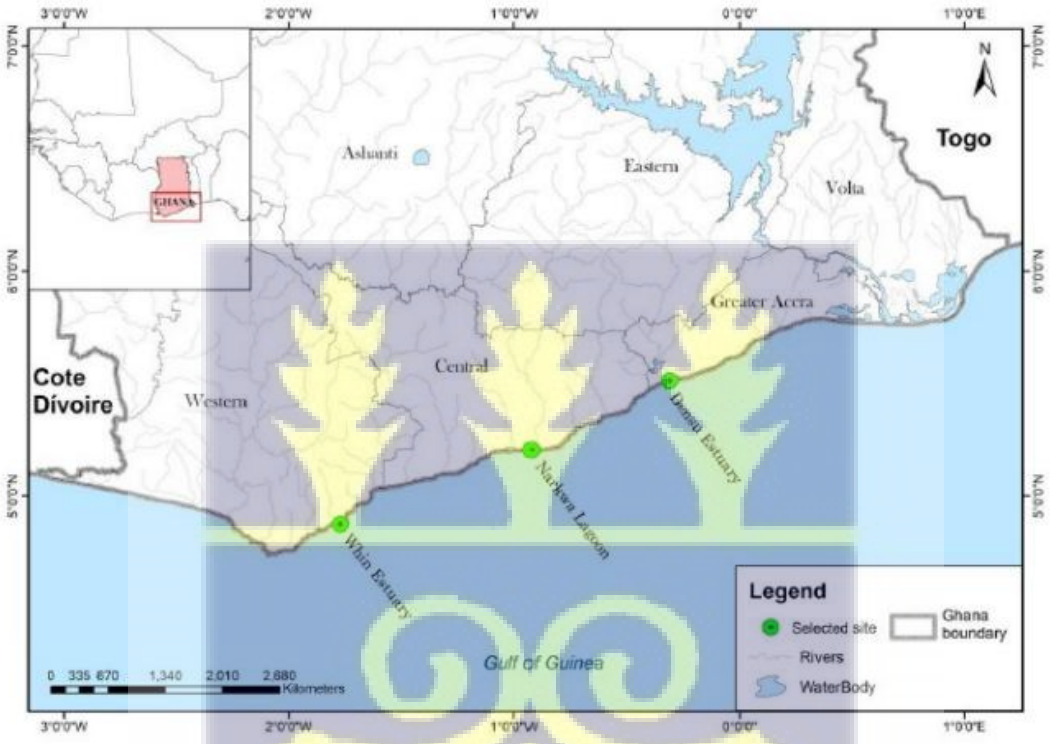


Figure 4.1: Selected estuarine sites along the coast of Ghana in the study

4.2 Sample size determination

The sample size was calculated will the aim of detecting a moderate effect size of 0.3 in mean haemoglobin concentration among women at any two of the three study sites, with 80% power and a two-sided significance level of 5%. An effect size of 0.3 corresponds to a difference of approximately 0.3–0.5 g/dL in haemoglobin levels, which is regarded as clinically meaningful

in population-level studies (Andrykowski et al., 2005). This analysis led to a target sample size of 184 women per site, culminating in a total of 552 participants across the three estuarine locations. Regarding the oyster samples, the study aimed to accurately measure nutrient composition, necessitating a larger-than-usual sample size to accommodate food heterogeneity (Greenfield & Southgate, 2003). A total of 915 oyster samples were collected (305 per site), drawing on formative data regarding oysters as reported by Abreu et al. (2020), in accordance with recommendations from the FAO for nutritional assessments in heterogeneous food groups (Greenfield & Southgate, 2003).

4.3 Sampling protocols

Leaders of women's shellfisher groups facilitated the sampling of participants. In areas without formal women's groups, local guides or key informants assisted field staff in generating databases of women shellfishers (Kuhnlein, 1986). These databases served as the sampling frames for each site and were validated using the inclusion criteria: women aged 15–49, actively involved in oyster harvesting, processing, or retailing, and residents of their communities for at least six months. Pregnant women were excluded. Due to the small number of eligible participants relative to the estimated sample size, all women shellfishers who met the inclusion criteria were interviewed.

Oysters were collected using a convenience sampling approach, which is a recommended strategy for dealing with uncultivated and wild food sources that exhibit variability in size, maturity, and nutrient composition (Greenfield & Southgate, 2003). Research assistants, supported by local guides, collected oysters from designated quadrat areas (20 m^2) within established harvesting locations at each site. The larger samples from each site were thoroughly mixed, and the requisite quota was randomly selected for laboratory analysis. The oysters were cleaned, separated from

their shells, and stored in airtight containers on ice prior to transportation to the laboratory for mineral content analysis (Baggett, 2014).

4.4 Study Variables

4.4.1 Independent Variables

The study trained a team of six field assistants and a supervisor to assist in the data collection process. The training encompassed crucial areas such as research ethics, questionnaire administration, and the standardisation of data collection tools, including the Haemocue and Secca weighing scale. Subsequently, a thorough assessment was conducted to evaluate their performance prior to their deployment for the pretesting of the questionnaires in the field. All interviews were conducted in person at the homes of participants within the communities. These locations were selected to ensure participant comfort, privacy, and minimal disruption to their daily activities. Interviews were conducted in local languages (Ga, Twi, or Fante) by trained enumerators who were familiar with the cultural context of each site. The main independent variable was the estuarine site. Potential covariates included socioeconomic characteristics such as education, occupation, household assets, marital status, age, number of children, and household size. The Poverty Probability Index (PPI) was also included to assess the likelihood of participants living below the poverty line (IPA, 2019).

4.4.2 Dependent Variables

Anaemia and Overweight/obesity: Overweight/obesity status was determined using participants' Body Mass Index (BMI). BMI was classified into a binary outcome: normal weight (≤24.9 kg/m²) and overweight/obese (≥25 kg/m²) (WHO, 2022). Anaemia was defined as Hb levels below 12 g/dl for non-pregnant women (WHO, 2021b).

Dietary Intake: The study conducted an estimation of the participants' nutrient intake (dietary minerals and calories) based on the foods they consumed within a 24-hour period. Nutrient and calorie intake were evaluated using a validated 24-hour recall questionnaire in the short term (Głąbska et al., 2016; Serra-Majem et al., 2010). Data was collected twice (on a weekday and one weekend day). Participants provided a comprehensive list of all the foods and beverages consumed within the past 24 hours, utilizing commonly used household measures in the area, such as cups, ladles, spoons, and models made of wood and plastic for fish, bread, sausage, orange, and corn to provide estimated quantities consumed. Subsequently, the reported portion sizes provided by the participants were converted into grams using food weights and entered into the Ghana Food Nutrient Database (GFND) to estimate the nutrient composition (Armah et al., 2012). Instances where food items were not listed in the GFND, the USDA and West African reference tables were utilized (USDA, 1987, 2020a; Vincent et al., 2020). In total, the 55 food items consumed by participants were grouped by nutritional composition into eleven categories (**Supplementary sheet 1**): grains and tubers, vegetables, fruits, dairy products, animal-source proteins, fats and oils, sweets, beverages, mixed dishes, and condiments/spices for further analysis. Principal Component Analysis was used to identify two dietary patterns with a loading factor of ≥0.3: an energy-dense pattern, characterised by higher intakes of grains, tubers, dairy, sugars, and beverages; and a nutrient-rich pattern, marked by higher consumption of mixed dishes, animal proteins, and fruits, and inversely associated with discretionary items and condiments (**Supplementary sheet 2 & 3)**. These patterns explained 20.5% and 16.5% of the total variance in dietary intake, respectively. To evaluate the relationship between dietary patterns and health outcomes, participants' nutrient intake scores were calculated and subsequently categorised into tertiles: lower, middle, and upper. This categorisation involved ranking participants' total nutrient coefficients in ascending order and

dividing them into three equal groups based on the distribution of the nutrient coefficients across the entire sample.

Food Insecurity: The Household Food Insecurity Access Scale (HFIAS) was used to assess food insecurity, classifying households as food-secure, or having mild, moderate, or severe food insecurity (Coates et al., 2007).

4.5 Laboratory Analysis

Oyster samples were digested using a solution of 10 ml nitric acid (HNO_3) and 5 ml sulfuric acid (H_2SO_4) to achieve complete dissolution of both organic and inorganic matter. The mixture was then heated to 95°C for 1-3 hours until the substrate darkened. After cooling, 2 ml of 30% hydrogen peroxide (H_2O_2) was added to oxidize remaining carbon compounds, which were converted to carbon dioxide (CO_2) and evaporated. This process yielded a clear solution, which was diluted with distilled water to a final volume in a 100 ml volumetric flask for mineral analysis (Cho & Nielsen, 2017). Total phosphorus was determined using UV-visible spectrophotometry, wherein the intensity of colour developed after the addition of specific reagents was measured to quantify phosphorus content. Other mineral elements, including calcium, iron, zinc, copper, and others, were analysed using atomic absorption spectrometry (PinAAcle 900T Perkin Elmer, Kentucky, USA) with an air-acetylene flame as the fuel source (Edgell, 1989; USEPA, 1989). All measurements were performed in triplicate to ensure accuracy, and the average values were used for analysis. To ensure the reliability and precision of the data, the field assistants underwent comprehensive training on questionnaire administration, ethical protocols, and data collection methodologies. Pre-testing of the questionnaire was conducted in James Town, a community with socioeconomic characteristics similar to the study sites, to identify and address any issues before

the main study. Additionally, Certified Reference Material (IAEA 461), a marine biota sample (Clam, *Gafrarium tumidum*), was used as part of the quality control process for oyster sample analysis. The percentage recovery of the analysed metals ranged from 92.6% to 101.7%, demonstrating high accuracy and consistency in the analytical procedures (Supplementary sheet 4).

4.6 Data Analysis

Data were analysed using IBM SPSS Statistics (Version 27.0, Armonk, NY: IBM Corp.). Descriptive statistics, including means, standard deviations, frequencies, and percentages, were used to summarize the background characteristics such as demographic and socioeconomic variables. BMI and Hb were analysed using analysis of covariance (ANCOVA) to compare values across estuary sites, with adjustments for age, education, and parity. Post-hoc analysis (Tukey-Kramer) was used for the pairwise comparison between the sites. Logistic regression was employed to identify predictors of nutritional status and food insecurity.

- **Overweight/obesity and anaemia:** Pearson's Chi-square test was used to compare differences in the prevalence of anaemia and overweight/obesity across the study sites. Additionally, analysis of covariance (ANCOVA) was used to compare the haemoglobin (Hb) and BMI scores across the sites. Binary logistic regression was performed to identify factors associated with anaemia and overweight/obesity in two separate models. Results were presented as odds ratios (OR) with 95% confidence intervals.
- **Dietary Patterns:** Principal Component Analysis (PCA) in SPSS version 27 was applied to identify common dietary patterns among women. Two key dietary patterns were extracted from two non-consecutive 24-hour recalls, conducted seven days apart.

- **Mineral Concentration:** analysis of variance (ANOVA) was used to determine differences in mean mineral concentrations across the estuary sites.
- **Public Health Risk Assessment:** The study assessed health risks associated with oyster consumption using the Target Hazard Quotient (THQ) for non-carcinogenic effects and the Target Cancer Risk (TCR) for carcinogenic effects, based on heavy metal content in the oysters. Risks were classified according to the thresholds defined by the USEPA . (USEPA, 2014; Wang et al., 2018).

PART THREE: RESULTS

Part Three presents 4 chapters in journal-style format addressing the four specific objectives listed above.

CHAPTER 5: Specific Objective One

Prevalence of Food Insecurity among Women Shellfishers of Reproductive Age across Selected Estuarine Sites in Ghana

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Abstract

Background: Food insecurity in Ghana has significantly worsened over the past decade, leading to rising hunger and malnutrition, particularly among women. Women shellfishers may be at increased risk of food insecurity, in part due to the gradual degradation of mangrove and estuarine ecosystems that support their livelihoods. This study aimed to compare the prevalence and determine the factors associated with household food insecurity among women shellfishers across three selected estuarine sites in Ghana.

Methods: This was a cross-sectional study. Data were collected between June and July 2021. Participants were women of reproductive age (15–49 years) who were engaged in oyster harvesting, processing, and retailing (hereafter, women shellfishers) at three selected estuarine sites, namely Densu, Narkwa-Lagoon, and Whin. Food insecurity was measured using the Household Food Insecurity Access Scale. We used descriptive statistics to summarize socio-demographic characteristics, a Chi-Square test to compare prevalence rates, and logistic regression analysis to identify factors associated with household food insecurity, with significance set at $p < 0.05$.

Results: In total, 504 women shellfishers participated in the study. The prevalence of household food insecurity was high but not significantly different across the estuarine sites: 93.5% in Densu, 93.1% in Narkwa, and 88.5% in Whin (p=0.218). Overall, 92.1% of all women shellfishers were food insecure, with 78.6% experiencing severe food insecurity, 11.1% moderate,

and 2.4% mild. Food insecurity was associated with the Densu estuarine site (aOR=3.14; CI: 1.18-8.33; p=0.022) and inversely associated with household asset ownership (aOR=0.73; CI: 0.54-0.98; p=0.037). However, household poverty rate (aOR=1.04; CI:0.98-1.10; p=0.237) and oyster intake (aOR=1.47; CI: 0.40-5.47; p=0.565) were not significantly associated with household food insecurity.

Conclusion: Many women along Ghana's coastline reported high household food insecurity. It is therefore important to develop gender-sensitive strategies to support them during off-seasons and enhance oyster production in the estuaries.

Keywords: food insecurity, factors, women, estuarine site, oysters.

5.1 Background

Food insecurity is a global issue. Many people lack equal access to nutritious, affordable food, driving a growing crisis of hunger and malnutrition (GPAFSN, 2016; WHO, 2020). Millions now experience food insecurity and undernutrition, while overnutrition is also on the rise. This "double burden of malnutrition" is particularly severe in developing countries, where economic hardship drives people to choose cheap, calorie-dense foods over nutritious options (FAO, 2021b; Global Nutrition Report, 2021). The COVID-19 pandemic has worsened these conditions, disrupting supply chains, causing job losses, and deepening income insecurity, further threatening food access (Adusei, 2021; Ayanlade & Radeny, 2020; WFP et al., 2020). Globally, about 30% of the population faces food insecurity, with the most severe impacts in Asia and Africa. In Africa, over 60% of the population is food insecure (FAO, 2021a; FAO et al., 2023). Ghana is grappling with worsening food insecurity, where recent reports show it has more than doubled, affecting nearly half of households (CFSVA, 2022; GSS, 2022). This problem is especially severe along the coastal

belt, where fishing communities are particularly vulnerable. The degradation of vital ecosystems, including mangroves and estuaries, which provide habitats for fish and shellfish, further compounds food insecurity in coastal areas. Human activities such as waste disposal, agricultural chemicals, and artisanal mining have damaged these ecosystems, reducing shellfish production and threatening the livelihoods of women who rely on shellfish for food and income (Chuku et al., 2020; Osei et al., 2021a). Socioeconomic pressures, combined with environmental degradation, limit these women's ability to ensure household food security. Efforts to promote sustainable management, including mangrove restoration and seasonal fishing closures, have been introduced to protect these ecosystems. However, these interventions may inadvertently increase food insecurity by restricting access to critical food sources like oysters during closed seasons. Artisanal fishing, which employs around 10% of Ghana's population, is a primary source of livelihood along the coast, and the shellfish sector alone engages about 4,000 people, mostly women, who harvest, process, and sell oysters for household consumption and income (Chuku et al., 2020). Women are disproportionately affected by food insecurity, especially in developing countries where they have less access to resources than men (Broussard, 2019; Jung et al., 2017; Matheson & McIntyre, 2014). The degradation of estuarine and mangrove ecosystems exacerbates the vulnerability of women shellfishers, whose livelihoods are directly tied to these resources (Chuku et al., 2020). Understanding the food security challenges, they face is crucial for developing policies that balance environmental conservation with the livelihoods and nutritional needs of these communities. While previous research has largely focused on the economic benefits and consumption patterns of shellfish like oysters, little has been done to assess the food insecurity status of women shellfishers, particularly in relation to ecosystem degradation and changing fishing regulations (Agbekpornu et al., 2021; Ampofo-Yeboah, 2014; Chuku et al., 2020). Given

the FAO's warning of worsening food insecurity among vulnerable populations in the wake of the COVID-19 pandemic (FAO et al., 2021), more research is needed on the food insecurity of women shellfishers. This study aims to fill this gap by examining the prevalence and predictors of food insecurity among women shellfishers across three selected estuarine sites in Ghana.

5.2 Methods

5.2.1 Study design, setting, and participants

This cross-sectional study was conducted at three estuarine sites: the Bortianor-Tsokomey-Tetegu area in the Greater Accra Region (Densu estuary), the New Amanful-Apremdo-Beahu area in the Western Region (Whin estuary), and Ekumfi Narkwa in the Central Region (Narkwa Lagoon). These locations were purposively selected based on the involvement of women in shellfish harvesting, their reliance on mangrove ecosystems for sustenance, and the level of ecosystem degradation and fishery health status. The Densu estuary is situated in the Ga South District of the Greater Accra Region, near the Bortianor community, approximately 13 kilometres from the city centre of Accra. It covers about 5,892 hectares and was designated as a Ramsar site in 1992 to protect its wetlands (Janha et al., 2017a). Despite this designation, the estuary is heavily degraded, threatening the livelihoods of local communities, primarily involved in fishing and shellfish harvesting. The Bortianor-Tsokomey-Tetegu area, home to a population of approximately 34,453 people, is diverse, with the majority being Ga and Ewe ethnic groups (GSS, 2014c). Oyster harvesting in the Densu estuary is regulated, with seasonal yields estimated at 8,816 kg per shell fisher (Osei et al., 2021b). In addition to shellfish harvesting, the residents engage in vegetable farming and cassava cultivation (Danso, 2013). Narkwa Lagoon is located in the Central Region, serves as the second study site. The lagoon, surrounded by the Narkwa community, spans 110

hectares of mangrove vegetation. It is formed by the convergence of two tributaries of the Okye River, which meet the sea (Chuku et al., 2020). The main economic activity in Narkwa is artisanal marine fishing, with women playing a significant role in oyster harvesting, processing, and selling. Seasonal oyster yields from the lagoon are estimated at 10,859 kg per person (Osei et al., 2021b). The Ekumfi Narkwa community, with a population of 4,634 people, also relies on salt production from the lagoon, and the area is known for its tourism potential (Chuku et al., 2020; Global Brigades, 2022). The Whin estuary, located in the Ahanta West District of the Western Region, was the third study site. This estuary is accessed through the New Amanful community, approximately 1.5 kilometres from Takoradi Airport (Chuku et al., 2020). Several communities, including Apremdo, Beahu, and New Amanful, rely on the estuary for their livelihoods, with a combined population of 20,009 (GSS, 2014a, 2014b). The Whin estuary stands out due to its relatively healthy and dense mangrove vegetation, which provides natural protection from environmental degradation (Chuku et al., 2020). Women in these communities are actively involved in oyster harvesting, with an estimated annual yield of 6,960 kg per person, making it one of the most productive estuaries after the Volta estuary (Osei et al., 2021b). In addition to shellfish harvesting, women in Whin engage in farming and trading during the rainy season (Duguma et al., 2022). Overall, these sites were chosen due to their varying levels of ecosystem health and degradation, reflecting different challenges and opportunities for women involved in shellfish harvesting. The combination of fishing, farming, and other livelihood activities, alongside tourism, underscores the economic importance of these estuaries to local communities.

The study targeted women aged 15 to 49 living in communities surrounding three estuarine sites, who were actively involved in activities related to the estuary and mangrove ecosystem, such as harvesting, processing, and selling oysters. Participants were required to have lived in their

respective communities for at least six months and provided informed consent by signing a consent form. The sample size was calculated to detect a moderate effect size of 0.3 in the average food insecurity score between any two estuarine sites. With a significance level of 0.05 (two-sided) and a power of 0.80, 184 participants per estuarine site were needed, totalling 552 women shellfishers.

5.2.2 Sampling procedures

In the Densu estuarine site, communities had organized women's groups in the oyster value chain with established leadership. These leaders provided a database of shellfishers, including women of various ages as well as pregnant and lactating women involved in the oyster value chain. This database was validated based on the study's inclusion criteria. In contrast, in the Narkwa and Whin estuarine sites, where no formal groups existed, key informants assisted field workers in creating a database of women shellfishers. Due to the small number of eligible participants relative to the estimated sample size, the study interviewed all women shellfishers who met the inclusion criteria. Ethical approval was obtained from the Ghana Health Service Ethics Committee (Ref. No: GHS-ERC 015/12/20).

5.2.3 Independent variables

We administered a structured questionnaire (Supplementary file) to women shellfishers within their homes to collect data on sociodemographic characteristics, including estuarine site, age, education, occupation, marital status, oyster intake, and whether they received in-kind or cash payments for any work performed in the month preceding the interview. Additionally, we gathered information on household characteristics, such as the total number of children under the care of participants, household size, household asset ownership, and the poverty ratio using the Poverty

Probability Index (PPI). The PPI utilized in this study was based on the nationally standardized questionnaire for Ghana, developed by Innovations for Poverty Action (IPA) in 2019 (IPA, 2019). It is noteworthy that canoe ownership was not included as a parameter in the PPI tool, as the index relies on a fixed set of ten nationally validated indicators of household assets and characteristics: region of residence, household size, housing materials, and the capacity to purchase food items such as eggs and beef within the preceding month. Each variable is assigned a score to estimate the likelihood of living below the national poverty line; lower scores indicate a higher probability of poverty. Consequently, while canoe ownership may be relevant to the fishing livelihoods of artisanal fishers, it could not be incorporated into the PPI score. This omission did not bias the results, as the PPI is designed to facilitate comparability across households nationwide, utilizing only the standardized indicators established during its development. Additionally, the scores for household assets, which include canoes, refrigerators, televisions, fans, smartphones, and gas stoves, were documented and estimated independently for further analysis.

5.2.4 Measurement of outcome and exposure variables

The Household Food Insecurity Access Scale (HFIAS) was used to assess the food insecurity status of shellfishers' households, following the methodology described by (Coates et al., 2007). The scale consists of two sections: occurrence and frequency-of-occurrence, each with 9 items. An affirmative response to the occurrence question was coded as 1, while a negative response was coded as 0. For households that answered affirmatively, frequency-of-occurrence was scored from 1 to 3 based on how often the condition occurred. The HFIAS evaluates three key domains: anxiety/uncertainty about food, poor food quality, and insufficient food consumption. These domains help capture the extent and frequency of food insecurity. The HFIAS score serves as a

continuous measure of household food access over the past 30 days. For each household, the sum of frequency-of-occurrence responses for all 9 questions was calculated, yielding a score between 0 and 27. Higher scores indicate greater food insecurity. The average HFIAS score was determined by dividing the total score by the number of participating households per estuarine site and overall. To classify households into different food insecurity levels, the Household Food Insecurity Access Prevalence (HFIAP) indicator was used. Households were categorized as food secure, mildly, moderately, or severely food insecure based on their responses. Food-secure households experienced no or rare worry about food access (Q1a=0 or Q1a=1). Mildly food-insecure households occasionally worried about food, had a monotonous diet, or ate undesirable foods infrequently (Q1a=2 or Q2a=1). Moderately food-insecure households frequently compromised food quality and sometimes reduced meal sizes (Q3a=2 or Q5a=1). Severely food-insecure households experienced the most extreme conditions, such as running out of food or going an entire day without eating (Q7a=1 or Q9a=1), even if these occurred rarely. Households that experienced any of these severe conditions in the last four weeks were classified as severely food insecure (Coates et al., 2007).

5.2.5 Statistical Analysis

Data were analysed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including percentages or means, and standard deviations, were used to summarise the sociodemographic characteristics and food insecurity status of women shellfishers. Food insecurity status was classified into four categories according to FAO guidelines (Coates et al., 2007): (1) overall food insecurity, (2) mild food insecurity, (3) moderate food insecurity, and (4) severe food insecurity. Pearson's Chi-square test was applied to

assess significant differences in food insecurity rates, and analysis of variance (ANOVA) was used for the HFIAS scores across the estuarine sites. However, for the regression model, household food insecurity was broadly categorised as a binary outcome (yes/no). Bivariate analysis examined the relationship between the covariates and household food insecurity at a significance level of $p < 0.3$ (Abubakari et al., 2015). This threshold was intentionally established to be more inclusive, thereby minimising the risk of excluding potentially important covariates that may demonstrate weak associations during the bivariate stage but could attain statistical significance upon adjustment for confounding variables in the multivariable analysis (Malhotra, 2020). Estuarine site, oyster consumption, household assets, poverty rates, and payment in the past week were treated as fixed factors in the model. An overarching multivariate model was subsequently constructed, incorporating these independent variables and food insecurity, with a significance level set at $p < 0.05$. However, occupation of women and the status of payment received in past week were negatively and highly correlated ($r = -0.921$, $p < 0.001$). Payment received in kind or cash was retained in the model due its higher coefficient. The interaction terms were not significant for household asset score ($p < 0.377$), poverty line ($p < 0.201$), and the number of children per women ($p < 0.568$), therefore were retained in the model. Multiple regression analysis was then performed on the primary independent variables (estuarine site, oyster consumption, household assets, household poverty rates, and payment received in the past week for any work done) and household food insecurity, retaining covariates with a significance level of $p < 0.3$ from the bivariate analysis. Results of the final model were reported as odds ratios, with a significance threshold of $p < 0.05$.

5.3 Results

5.3.1 Background characteristics of women shellfishers

Table 4.1 summarizes the background characteristics of 504 women shellfishers from Densu (200), Narkwa (174), and Whin (130) estuarine sites, representing 85.6% response rate. The mean age of the women was 31.6 ± 9.1 years, with no significant difference across sites. A minority (36.5%) were aged 25-34 years. Education levels varied significantly: 81% of women in Densu had attended school compared to 70% in Whin and 57% in Narkwa. However, secondary education attainment was higher in Whin (52%) than in Densu (44%) and Narkwa (25%). The school life expectancy was longest in Densu (5.7 ± 3.8 years) compared to Whin (5.6 ± 4.3) and Narkwa (3.5 ± 3.5). Literacy rates were highest in Densu (51%), followed by Whin (50%) and Narkwa (34%). Married women were more prevalent in Narkwa (68%) than in Densu (63%) and Whin (50%). Skilled labour was significantly higher in Densu (23%) compared to Whin (11%) and Narkwa (6%). More women in Whin (64%) had worked for cash or in-kind in the past week, compared to Densu (61%) and Narkwa (39%). The average number of children per household was 3.5 ± 2.1, and household size averaged 6.1 ± 2.5 members. Narkwa had the largest households (4.0 ± 2.1 children and 6.5 ± 2.2 members), while Densu had the smallest (2.9 ± 1.5 children and 5.5 ± 2.3 members). Canoe ownership was reported in 10% of households. Asset ownership averaged 1.8, with Narkwa having the fewest (1.1) and Densu the most (2.2). The overall household poverty rate among the women was 13.2%, with 23% of households in Narkwa, 9.2% in Whin, and 7.2% in Densu.

Table 4.1: Demographic and socioeconomic characteristics of women shellfishers

Variables	Estuarine sites			Total
	Densu	Narkwa	Whin	
Age				
Mean (±SD)	32.2 ± 8.5	30.8 ± 9.4	31.9 ± 9.7	31.6 ± 9.1
≤ 24 years	44 (22)	48 (27.6)	33 (25.4)	125 (24.8)
25 - 34 years	73 (36.5)	59 (33.9)	38 (29.2)	170 (33.7)
35 - 44 years	66 (33)	53 (30.5)	42 (32.3)	161 (31.9)
45+ years	17 (8.5)	14 (8.0)	17 (13.1)	48 (9.5)
Ever attended school	161 (80.5)	100 (57.5)	91 (70.5)	352 (70)
Attained at least secondary education	87 (43.5)	43 (24.7)	68 (52.7)	198 (39.4)
School life expectancy, years	5.7 ± 3.8	3.5 ± 3.5	5.6 ± 4.3	4.9 ± 4.0
Literacy[a]	101 (50.5)	59 (34.1)	65 (50.4)	225 (44.8)
Currently married	125 (62.5)	119 (68.4)	65 (50.0)	309 (61.3)
Received payment in past week (paid in cash or kind)[b]	121 (60.5)	68 (39.1)	83 (63.8)	272 (54.0)
Additional Occupations				
Skilled labour	28 (14.0)	4 (2.3)	9 (6.9)	41 (8.1)
Unskilled labour	52 (26.0)	46 (26.4)	57 (43.8)	155 (30.8)
Owned a shop or business[c]	42 (21.0)	18 (10.3)	17 (13.1)	77 (15.3)
Not working	78 (39.0)	106 (60.9)	47 (36.2)	231 (45.8)
Currently breastfeeding a child	26 (13.8)	43 (27.6)	23 (19.7)	92 (19.9)
Parity	2.6 ± 1.8	3.6 ± 2.6	3.2 ± 2.3	3.1 ± 2.3
Total number of children	2.9 ± 1.5	4.0 ± 2.1	3.9 ± 2.7	3.6 ± 2.1
Members of households	5.5 ± 2.3	6.5 ± 2.2	6.5 ± 3.1	6.1 ± 2.5
Owned a canoe	20 (10)	20 (11.5)	13 (10.0)	53 (10.5)
Household assets' score[d]	2.2 ± 1.7	1.1 ± 1.3	2.0 ± 1.6	1.8 ± 1.6
Poverty ratio[e]	0.07	0.23	0.09	0.13

Values presented are means or proportions of participants contributing to the specific variables per estuarine site.
[a]Include all the years participants spent schooling, counting from primary one as a complete academic year.
[b]Include both in kind and cash payment received from any work done by the participant.
[c]Includes participants operating provision shops, household table-top, and any form of established trading.
[d]indicates number of household items (refrigerators, televisions, fans, smartphones, and gas stoves) owed
[e]Reflects the likelihood of household poverty, estimated from the poverty probability index (IPA, 2019).

5.3.2 Prevalence of household food insecurity

Table 4.2 presents the food insecurity status of the women shellfishers, revealing a high prevalence of food insecurity. Among the participants, 92.1% experienced some level of food insecurity, with 78.6% classified as severely food insecure, 11.1% as moderately food insecure, and 2.4% as mildly food insecure. Key indicators included consuming undesired food (80.2%), concerns about insufficient household food supplies (77.8%), limited access to preferred foods (76%), inadequate portions (75.4%), running out of food (69.8%), and reduced meal frequency (69.4%). Although the overall food insecurity prevalence did not significantly differ across estuarine sites [Densu - 93.5%, Narkwa - 93.1%, Whin - 88.5%, $p = 0.218$], notable site-specific differences were observed. Severe food insecurity was significantly higher in Narkwa (83.3%) compared to Whin (81.5%) and Densu (72.5%) ($p = 0.025$). Similarly, moderate food insecurity varied significantly across the sites: 18.0% in Densu, 8.0% in Narkwa, and 4.6% in Whin ($p < 0.001$).

Table 4.2: Prevalence of food insecurity among women shellfishers

Indicators	Estuarine sites			P-value	Total
	Densu	Narkwa	Whin		
Q1: Worried HH would not have enough food	159 (40.6)[a]	144 (36.7)[b]	89 (22.7)[c]	0.009	392 (77.8)
Q2: HH not able to eat preferred foods	157 (41.0)	134 (35.0)	92 (24.0)	0.259	383 (76.0)
Q3: HH ate limited variety of foods	142 (47.2)[a]	98 (32.6)[b]	61 (20.3)[c]	<0.001	301 (59.7)
Q4: Ate some foods they did not want to eat	166 (41.1)[a]	144 (35.6)[b]	94 (23.3)[c]	0.034	404 (80.2)
Q5: Ate a smaller meal than needed	144 (37.9)	138 (36.3)	98 (25.8)	0.268	380 (75.4)
Q6: Ate fewer meals in a day	135 (38.6)	125 (174)	90 (25.7)	0.664	350 (69.4)
Q7: Ever no food to eat of any kind	122 (34.7)[a]	129 (36.6)[b]	101 (28.7)[c]	0.002	352 (69.8)
Q8: Slept at night hungry	89 (35.3)[a]	100 (39.7)[b]	63 (25)[c]	0.041	252 (50.0)
Q9: Gone a whole day and night without eating	55 (45.1)	41 (33.6)	26 (21.3)	0.292	122 (24.2)
Food insecurity status of women					
HFIAS score	11.7 ± 5.9	12.6 ± 6.6	10.9 ± 6.6	0.069	11.8 ± 6.3
Food secure	13 (6.5)	12 (6.9)	15 (11.5)	-	40 (7.9)
Overall household food insecurity status	187 (93.5)	162 (93.1)	115 (88.5	0.218	464 (92.1)
Severe household food insecurity	145 (72.5)[a]	145 (83.3)[b]	106 (81.5)[c]	0.025	396 (78.6)
Moderate household food insecurity	36 (18.0)[a]	14 (8.0)[b]	6 (4.6)[c]	<0.001	56 (11.1)
Mild household food insecurity	6 (3.0)	3 (1.7)	3 (2.3)	0.712	12 (2.4)

Different subscript letters denote estuarine sites differ significantly from each other at the 0.05 level in Pearson's chi-square test or in the analysis of covariance.

5.3.3 Factors associated with household food insecurity

The bivariate analysis revealed significant associations between household ownership of a canoe, household assets, poverty rate, and food insecurity (Table 4.3). Women shellfishers from households that owned a canoe were found to be twice as likely to experience food insecurity compared to those without one (cOR= 2.33; 95% CI: 1.01-5.36; p = 0.047). Additionally, an increase in household assets was associated with a 32% decrease in food insecurity among women shellfishers (95% CI: 0.56–0.83; p < 0.001). A 1-point increase in household poverty rate was significantly linked to a 6% increase in overall household food insecurity (cOR= 1.06; 95% CI: 1.02–1.10; p = 0.006). However, neither the estuarine sites (Densu: p = 0.113, Narkwa: p = 0.163) nor oyster consumption (p = 0.619) were significantly associated with household food insecurity in the bivariate analysis. After adjusting for individual and household characteristics, a significant effect on the odds of household food insecurity was observed in one of the three estuarine sites. Specifically, women shellfishers from the Densu estuarine site were approximately three times more likely to experience household food insecurity compared to those from the Whin estuarine site (aOR = 3.14; 95% CI: 1.18–8.33; p = 0.022). The model also demonstrated that limited household assets increased the odds of food insecurity. A unit increase in household assets reduced the odds of household food insecurity by 27% (95% CI: 0.54–0.98; p = 0.037). The adjusted model did not find significant associations between oyster intake, marital status, age groups, secondary education, employment status, lactation, number of children, household size, and household food insecurity. For example, women shellfishers who had completed at least secondary education had a non-significant 54% reduction in the odds of food insecurity compared to those without secondary education (95% CI: 0.22–1.32; p = 0.175). Similarly, oyster consumption was not significantly associated with food insecurity (95% CI: 0.40-5.47; p = 0.565). Women shellfishers

who were currently married had 64% lower odds of household food insecurity compared to those who were never married, but this result was not statistically significant (95% CI: 0.06–1.21; p = 0.086).

Table 4.3: Crude and adjusted odds of maternal factors associated with overall household food insecurity.

Variables	cOR	(95% C. I.)	Sig	aOR	(95% C. I.)	Sig
Estuarine sites						
Ref = Whin	1.00			1.00		
Densu	1.88	(0.86, 4.09)	0.113	3.14	(1.18, 8.33)	0.022
Narkwa	1.76	(0.79, 3.90)	0.163	1.06	(0.37, 3.02)	0.920
Oyster intake	1.31	(0.45, 3.82)	0.619	1.47	(0.40, 5.47)	0.565
Age groups						
Ref = 45+ years	1.00					
≤ 24 years	1.21	(0.40, 3.67)	0.743		-	
25 - 34 years	1.20	(0.41, 3.49)	0.736		-	
35 - 44 years	1.96	(0.63, 6.17)	0.248		-	
Marital status						
Ref = Never married	1.00			1.00		
Currently married	0.78	(0.37, 1.65)	0.513	0.26	(0.06, 1.21)	0.086
Previously married	4.84	(0.61, 38.68)	0.137	1.49	(0.12, 17.89)	0.755
Ever attended school	0.88	(0.44, 1.76)	0.721		-	
Attained at least secondary educ.	1.44	(0.75, 2.75)	0.274	0.54	(0.22, 1.32)	0.175
Literacy	1.12	(0.59, 2.15)	0.723		-	
Additional Occupations						
Ref = Not working	1.00					
Skilled labour	0.47	(0.16, 1.37)	0.164		-	
Unskilled labour	0.65	(0.30, 1.40)	0.273		-	
Owned a shop or business	0.65	(0.25, 1.66)	0.364		-	
Received payment in past week	1.65	(0.84, 3.23)	0.148	0.98	(0.42, 2.26)	0.957
Children in HH of woman	1.13	(0.92, 1.38)	0.263	1.08	(0.83, 1.41)	0.577
Household members	1.11	(0.96, 1.29)	0.147	1.13	(0.90, 1.43)	0.294
Owned a canoe	2.33	(1.01, 5.36)	0.047	1.07	(0.36, 3.19)	0.910
Total number of HH assets	0.68	(0.56, 0.83)	<0.001	0.73	(0.54, 0.98)	0.037
Poverty rate	1.06	(1.02, 1.10)	0.006	1.04	(0.98, 1.10)	0.237

Outcome variable is overall food insecurity (severe, moderate, and mild food insecurity). Crude odd ratio (cOR) and adjusted odd ratio (aOR) were statistically significant at 0.05level. Model was adjusted for maternal education, occupation, and marital status.

5.4 Discussion

5.4.1 Prevalence of food insecurity

Our study compared food insecurity among women shellfishers in three estuarine sites, finding that 92.1% experienced some level of insecurity: 78.6% severe, 11.1% moderate, and 2.4% mild. While overall prevalence was similar across sites, Densu showed significantly higher severe food insecurity, and moderate food insecurity varied notably between Densu and the other sites. Major indicators of food insecurity among participants included consuming undesired food, concerns about insufficient household food supplies, limited access to preferred foods, inadequate portions, running out of food, and reduced meal frequency. The findings align with previous reports of widespread food insecurity in Ghana, particularly in coastal regions (CFSVA, 2012). Contributing factors may include closed season for artisanal fishing during the study period and depleted shellfish populations from pollution and mangrove loss, reducing oyster yields and affecting women's livelihoods (Chuku et al., 2020). The Densu estuary, in particular, can no longer sustain sustainable oyster harvesting in some sites, lowering household income and food availability. Our results are consistent with prior studies in Ghana, where food insecurity among farming and fishing households ranged from 59% to 100% (Armah et al., 2019; Asuru, 2020; Djangmah, 2016; Lambon-Quayefio & Owoo, 2021). Similarly, high food insecurity rates were found in rural areas, especially among women of reproductive age (Broussard, 2019; Pandey & Fusaro, 2020; Syafiq et al., 2022). Rates in other African countries, such as Malawi (87%), Uganda (72-88.5%), and Tanzania (60%), are slightly lower but still high (Nantale et al., 2017; Pereira et al., 2021). The impact of COVID-19 likely exacerbated food insecurity by disrupting supply chains, lowering incomes, and increasing food prices (Éliás & Jámbor, 2021; Hamadani et al., 2020), as the study coincided with the period when Ghana was emerging from its restrictions. Though the Ghanaian

government provided support (MFAD, 2022a, 2022b; MoF, 2020), to mitigate its impact and that of the closed fishing season, it was insufficient, particularly for the households of women in these communities.

5.4.2 Factors associated with household food insecurity

This study identifies two key factors associated with household food insecurity among women shellfishers, emphasizing the importance of socioeconomic factors, consistent with previous research (Leroux et al., 2018; Pandey & Fusaro, 2020; Smith & Frankenberger, 2018). Household asset ownership, serving as a proxy for wealth status, emerged as a strong factor associated with food insecurity among all women in the study. This finding aligns with Elsahoryi et al. (2020). Low income, compounded by rising food costs and limited access to affordable, nutritious foods, further aggravated food insecurity, especially in fishing communities where income from shellfish harvesting is critical for purchasing staples. Income inequality heightened women's vulnerability, reinforcing the protective role of household asset ownership, particularly for women shellfishers in the study Pandey and Fusaro (2020). Food insecurity varied by estuarine site, with women in the Densu area facing greater risks due to geographic and contextual factors. In this peri-urban setting, many women, predominantly migrant settlers, faced additional challenges, such as limited access to land for subsistence farming. This limitation increased their reliance on purchased staples, as they were unable to grow their own food. While studies often report higher food insecurity rates in rural areas (Janda et al., 2022; Phulkerd et al., 2023), the disproportionate impact of COVID-19 on urban and peri-urban centres (Éliás & Jámbor, 2021; Hamadani et al., 2020), may explain the heightened food insecurity risk among women in the Densu estuarine site compared to the other sites. Larger households, particularly those with more children, increased financial strain and impacted food access (Abdu et al., 2018; Felker-Kantor & Wood, 2012).

However, this study found no association between household size or number of children and food insecurity. Though in some cases, larger households may benefit from additional income earners or food producers (Sisha, 2020). Higher education levels are generally linked to reduced food insecurity (Grimaccia & Naccarato, 2022). However, this study revealed that most women lacked the educational qualifications necessary for stable employment, which diminished the protective effect of education. Similarly, neither canoe ownership nor the consumption of oysters was significantly associated with household food insecurity in this study. Although owning a canoe could enhance productivity and increase household income (Chen et al., 2023; Sisha, 2020), the study took place during the fishing close season, rendering this factor temporarily irrelevant to food insecurity. Similarly, despite the potential dietary benefits of oysters (Abreu et al., 2020), few shellfishers consumed them, as noted by Agbekpornu et al. (2021), which further limited their contribution to household food security in this study. Overall, the study underscores the multifaceted nature of food insecurity among women shellfishers, shaped by socioeconomic, geographic, and household factors. Empowering women through asset ownership and providing targeted support are essential steps toward improving food security outcomes.

5.5 Strength and Limitations

The study had several strengths and limitations that merit consideration. A notable strength was the inclusion of a large and diverse sample of women shellfishers from three distinct estuarine sites in Ghana (Densu, Whin, and Narkwa Lagoons). This diversity enhances the generalizability of the findings to comparable populations. By concentrating specifically on women shellfishers, this study addresses a significant gap in gender-specific research regarding coastal food security, offering nuanced insights into the unique livelihood challenges and vulnerabilities encountered by women in estuarine communities. Nevertheless, certain limitations must be acknowledged. The

cross-sectional study design restricts the ability to infer causal relationships, indicating that observed associations between factors and food insecurity may not necessarily imply causation. Furthermore, reliance on self-reported data regarding household food insecurity may have exaggerated participants' reported experiences, particularly given the heightened uncertainty associated with the COVID-19 pandemic at the time of the data collection. Moreover, the reliance on self-reported data concerning household food insecurity may have led to inflated reports of participants' experiences, particularly in light of the heightened uncertainty associated with the COVID-19 pandemic during the data collection period. Additionally, the smaller sample size in Whin (n=130) may have diminished the statistical power to detect site-specific associations, potentially underestimating differences between this site and others. The use of the HFIAS with its standard 30-day recall period captured food insecurity experiences at a single point in time but did not account for seasonal fluctuations in harvest yields, fishing closures, and market conditions that can influence food access. Consequently, the prevalence reported in this study may not accurately reflect conditions at other times of the year. Future research could extend the recall period or conduct repeated assessments across different seasons to provide a more comprehensive understanding of the dynamics of household food insecurity among this demographic.

5.6 Conclusion

The findings indicate that a majority of women who engage in shellfish harvesting face food insecurity. This can be attributed to various factors, including the impact of regulations on the fishery, and the declining shellfish population. These findings underscore the importance of taking into account factors such as household assets and the location of estuarine sites when assessing the food insecurity of women in coastal areas. Therefore, it is crucial to preserve the mangrove ecosystem to ensure the sustainable production of oysters. Additionally, there is a need for gender-

sensitive social protection for women during the closed season to mitigate the impact of household food insecurity.

Contribution of Authors

Francis Z. Taabia: investigation, writing - original draft, visualization. **Agartha N. Ohemeng:** writing - review & editing, supervision. **Seth Adu-Afarwuah:** conceptualization, funding acquisition, writing - review & editing. **Brietta M. Oaks:** funding acquisition, writing - review & editing.

Declaration of interest

The authors assert that they have no disclosed financial interests or personal relationships that may have exerted any influence on the findings of this study.

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CHAPTER 6: Specific Objective Two

Prevalence and factors associated with overweight/obesity and anaemia among women Shellfishers of reproduction age in selected estuarine sites in Ghana

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Abstract

Background: Anaemia, overweight, and obesity pose significant public health challenges among women of reproductive age. Women shellfishers are especially vulnerable, as the degradation of mangrove and estuarine ecosystems threatens their livelihoods and may impact their nutritional status. This study aimed to compare the prevalence and determine the risk factors associated with anaemia and overweight/obesity among women shellfishers.

Methods: This cross-sectional study was conducted between June and July 2021. Participants were women involved in oyster harvesting, processing, and retailing at three selected estuarine sites: Densu, Narkwa Lagoon, and Whin. A semi-structured questionnaire was used to collect data on diet and household characteristics. Overweight/obesity (≥30 kg/m²) and anaemia (<12 g/dl) status were assessed through anthropometric measurements and capillary blood samples. The Chi-square test was used to compare anaemia and overweight/obesity rates across sites, while multiple logistic regression determined factors associated with anaemia and overweight/obesity, with significance set at $p < 0.05$.

Results: In total, 504 women participated in the study. The prevalence of overweight/obesity varied significantly across estuarine sites: 58.3% in Densu, 27.6% in Narkwa, and 43.1% in Whin ($p<0.001$). Anaemia prevalence did not vary significantly across sites: 25% at Densu, 20% at Narkwa-Lagoon, and 15% at Whin ($p=0.068$). Factors associated with overweight/obesity

included maternal age below 24 years (adjusted odds ratio [aOR]=0.30; 95% CI: 0.11-0.85; p=0.006), being married (aOR=1.93; 95% CI: 1.10-3.40; p=0.027), household poverty (aOR=0.97; 95% CI: 0.95-0.99; p=0.011), and adherence to a nutrient-rich dietary pattern (aOR=1.68; 95% CI: 1.01-2.78; p=0.046). Anaemia was associated with being overweight (aOR=0.56; 95% CI: 0.32-0.98; p=0.002), obese (aOR=0.27; 95% CI: 0.12-0.61; p=0.041), and residing in Densu (aOR=2.24; 95% CI: 1.20-4.18; p=0.012).

Conclusion: The study found significant disparities in overweight/obesity rates among women in estuarine sites. Integrating obesity management strategies into reproductive health services is recommended to enhance maternal nutrition.

Keywords: anaemia, overweight and obesity, nutritional status, estuarine site, women shellfishers.

6.1 Background

Anaemia and overweight or obesity among women of reproductive age reflect a dual burden of malnutrition. These conditions highlight a complex interplay between undernutrition and overnutrition, particularly in developing regions. Micronutrient deficiencies, especially iron-deficiency anaemia, remain widespread, with global estimates showing a 30% prevalence among women of reproductive age and 36.5% among pregnant women (WHO, 2023b). Anaemia is particularly prevalent in Africa and Southeast Asia, where rates reach 39.8% and 46.5%, respectively (WHO, 2023b). In Ghana, anaemia affects 41.1% of women, with regional variations such as 38.8% in Greater Accra and 45.9% in the Western Region (GDHS, 2024). Simultaneously, the rising prevalence of overweight and obesity among women is an emerging public health issue.

Globally, 43% of adults are overweight, and 16% are obese (WHO, 2024). In Ghana, obesity rates have more than quadrupled since 1993, with over half of women of reproductive age now classified as overweight or obese. This trend is more severe in urban areas (69.7%) compared to rural areas (36.8%) (GDHS, 2024). The growing burden of overweight and obesity increases the risk of non-communicable diseases, including type 2 diabetes and cardiovascular diseases. In women of reproductive age, maternal obesity exacerbates birth complications such as preterm births, congenital abnormalities, and raises the likelihood of chronic diseases in offspring (Block et al., 2013; McDonald et al., 2010). In contrast, maternal anaemia elevates risks of miscarriage, postpartum haemorrhage, and maternal mortality, while contributing to stillbirths, preterm births, and low birth weights (WHO, 2023b). Additionally, anaemia can impair children's cognitive development, limiting their future potential. The rise in overweight and obesity is largely driven by structural factors. One key driver is the "nutrition transition," characterized by a shift toward highly processed foods and sedentary lifestyles, leading to reduced intake of nutrient-dense foods like fruits and vegetables (Global Nutrition Report, 2021; WHO, 2024). Limited access to opportunities for physical activity, coupled with increased reliance on motorized transport and labour-saving devices, further contributes to this growing issue (Bose et al., 2022; Brown et al., 2017; King & Jacobson, 2017). Socioeconomic disparities in education, income, and occupation further exacerbate malnutrition, particularly among women in developing regions (Agbeko et al., 2013; Lartey et al., 2019). Socioeconomic constraints limit access to nutritious foods, particularly for low-income populations (Drewnowski, 2018; Lartey, 2021). Women in developing countries are more vulnerable to nutrient deficiencies, including iron due to limited nutritional knowledge (Olatona et al., 2023). Despite economic growth (Ecker & Fang, 2016), some groups, like women shellfishers, still prioritize energy-dense diets due to food insecurity, putting them at higher risk

for both obesity and anaemia. Environmental degradation, particularly the loss of mangroves, threatens shellfishers' livelihoods, further exacerbating food insecurity (Chuku et al., 2020; Oteng-Ababio & Owusu, 2011). Oysters, rich in micronutrients and omega-3 fatty acids, could play a critical role in addressing anaemia and improving reproductive health, especially in coastal communities (Shahidi & Ambigaipalan, 2018; Swanson et al., 2012). Assessing the nutritional health of women in small-scale fisheries is crucial to understanding the specific challenges faced by this vulnerable group and aligns with Sustainable Development Goal 2, which aims to end hunger and ensure access to nutritious food for all. This study seeks to evaluate the prevalence and risk factors of anaemia, overweight, and obesity among women of reproductive age in three selected estuarine sites in Ghana, with the goal of informing future interventions to improve health outcomes for this population.

6.2 Methods

6.2.1 Study design, setting, and population.

This cross-sectional survey involved women of reproductive age (15–49 years) recruited from three estuarine sites along the coastal belt of Ghana: Densu, Narkwa, and Whin. The Densu Estuary, located in the Ga South District of Greater Accra, is bordered by the Gulf of Guinea to the south and neighbouring communities to the east and west, with hills to the north (Danso, 2013). The site included the Bortianor neighbourhood, divided into the Bortianor, Tettegu, and Tsokomey suburbs. Covering 5,892 hectares, it was designated as a Ramsar site in 1992 to protect its wetland ecosystem (Janha et al., 2017a). The area is primarily inhabited by the Ga and Ewe communities, with a population of 34,453 (GSS, 2014c). Fishing is the main occupation, along with vegetable cultivation and cassava farming. Densu is the only site where oyster harvesting is regulated due to

ongoing aquaculture efforts to enhance the oyster population (Osei et al., 2021b). The seasonal yield of mangrove oysters from Densu is estimated at 8,816 kg per harvester (Osei et al., 2021b). Narkwa Lagoon, situated in the Central Region of Ghana, surrounds the Narkwa community, from which it takes its name. Formed by two tributaries of the Okye River, the lagoon spans 110 hectares and features mangrove vegetation (Chuku et al., 2020). Bordered by coconut plantations, neighbouring communities, and the Gulf of Guinea to the east, the area's primary economic activities include artisanal fishing, shellfish trading by women, and farming. Narkwa also supports a salt production factory and serves as a regional tourist hub, with a population of 4,634 (Global Brigades, 2022). The site produces an estimated 9,512 kg of mangrove oysters per harvester annually (Osei et al., 2021b). The Whin Estuary in the Western Region serves as the third study site, accessible through New Amanful, 1.5 km from Takoradi Airport (Chuku et al., 2020). It encompasses the Apremdo, Beahu, and New Amanful communities, with a combined population of 20,009 (GSS, 2014a, 2014b). Women here are actively involved in shell fishing. The estuary is densely vegetated, providing both protection and yielding approximately 6,960 kg of mangrove oysters per season, per harvester. It also ranks as the second-highest income generator among the sites, with harvesters earning an estimated $626.30 monthly (Osei et al., 2021b). Unlike the other sites, Whin supports year-round oyster harvesting and is popular with tourists. Women here also engage in farming and trading (Duguma et al., 2022). Data were collected between June and July 2021. Ethical approval was granted by the Ghana Health Service Ethical Review Board (GHS-ERC 015/l2/20). Administrative permissions were secured from local authorities, including traditional chiefs and assembly representatives, as part of the community entry process at all sites. Approval was also obtained from the Densu Oyster Pickers' Association (DOPA) in Greater Accra

and key informants in the Narkwa and Whin sites. Written informed consent was obtained from all participants, and for those below 18 years, child assent and parental consent were required.

6.2.2 Sampling

The study assumed a moderate effect size in mean blood haemoglobin concentration among women shellfishers across different estuarine sites. Based on this, a sample size of 184 was calculated to achieve 80% power in detecting site differences at a 95% confidence level using a two-sided 5% test. As a result, a total of 552 women shellfishers from all three sites were surveyed in this study. In the Densu site, organized women's groups provided a database of shellfishers that formed the sampling frame. Local guides assisted field workers in profiling shellfishers at the Narkwa and Whin sites. Sampling frames for each site were validated using inclusion criteria: women aged 15–49, actively involved in oyster harvesting, processing, or retailing, and residents of their communities for at least six months. Pregnant women were excluded. Due to the limited number of women shellfishers relative to the estimated sample size, all available women who met the inclusion criteria were recruited for the study.

6.2.3 Data Collection

A structured questionnaire was administered to women shellfishers in their homes. It gathered data on sociodemographic characteristics, dietary intake, poverty probability index (PPI), household assets, and food insecurity status. Trained field assistants also measured and recorded each participant's weight and height. The initial step to ensure data quality involved providing field assistants with comprehensive training. The study trained a team of six field assistants and a supervisor to assist in the data collection process. The training encompassed crucial areas such as research ethics, questionnaire administration, and the standardisation of data collection tools,

including the Haemocue and Secca weighing scale. Subsequently, a thorough assessment was conducted to evaluate their performance prior to their deployment for the pretesting of the questionnaires in the field. All interviews were conducted in person at the homes of participants within the communities. These locations were selected to ensure participant comfort, privacy, and minimal disruption to their daily activities. Interviews were conducted in local languages (Ga, Twi, or Fante) by trained enumerators who were familiar with the cultural context of each site.

6.2.4 Socioeconomic and demographic data

The structured questionnaire was pretested in peri-urban settlements in James Town, Accra, which have similar socioeconomic profiles to the selected estuarine sites. A significant issue identified during pre-testing was participants' reluctance to provide finger-prick blood samples for haemoglobin (Hb) testing. Numerous women articulated concerns regarding pain, potential side effects, and mistrust concerning the utilisation of their blood samples. Consequently, the study enhanced the informed consent process by explicitly elucidating the purpose, benefits, and safety of the Hb test for the main data collection. Furthermore, we afforded participants the opportunity to observe and supervise the proper disposal of all examination materials following sample collection. Data were collected on individual and household demographics, including age, education, marital status, occupation, recent earnings (cash or in-kind), parity, number of children, household members, and lactation status. The study employed the Poverty Probability Index (PPI), a Ghana-specific tool for assessing poverty. The PPI consists of 10 questions related to household characteristics and asset ownership, covering variables such as region, household size, housing materials, and the ability to purchase food items like eggs and beef in the past month (IPA, 2019). Each variable is scored to calculate a household's PPI score, which estimates the likelihood of

living below the national poverty line. Lower scores indicate a higher probability of poverty. Given the nature of these fishing communities, canoe ownership vital for artisanal fishing was excluded from the PPI assessment. Instead, household asset ownership, including refrigerators, televisions, fans, smartphones, canoes, and gas stoves, was separately recorded and scored for the study.

6.2.5 Dietary Pattern

The dietary intake of women shellfishers was assessed using a 24-hour food recall, covering 55 food items sourced from the Ghana Food Composition Database (Armah et al., 2012). These items were grouped by nutritional composition into categories such as grains and tubers, vegetables, fruits, dairy products, animal-source proteins, fats and oils, sweets, beverages, mixed dishes, condiments, and spices (**Supplementary sheet 1**). Unlike typical dietary studies in Ghana, which use varimax rotation to derive uncorrelated dietary patterns (Frank et al., 2014; Galbete et al., 2017; Kushitor et al., 2023), this study employed Promax rotation to account for correlations between food items, reflecting real-life dietary habits. For example, foods like fizzy drinks and pastries, or the traditional "waakye" (beans and rice), are commonly consumed together (Kushitor et al., 2023). Despite significant correlations (Bartlett's test, $p < 0.001$), a low Kaiser-Meyer-Olkin (KMO) value of 0.496 raised concerns about sampling adequacy for factor analysis. Cronbach's Alpha was also low (0.518), indicating limited internal consistency of the identified patterns. To analyse dietary patterns, the frequencies of food items consumption from two non-consecutive 24-hour recalls (seven days apart) was standardized (0–1 scale) for principal component analysis in SPSS version 27. A loading factor of ≥0.3 was used to define food groups within two dietary patterns: an energy-dense pattern, marked by higher intakes of grains, tubers, dairy, sugars, and beverages; and a nutrient-rich pattern, characterized by mixed dishes, animal proteins, and fruits,

and inversely related to discretionary items and condiments. These patterns accounted for 20.5% and 16.5% of the total variance in dietary intake, respectively (**Supplementary sheet 3**). The study ranked participants' total food groups' coefficients derived from the PCA in ascending order, subsequently dividing them into three equal groups based on their distribution, and categorised them into tertiles: lower, middle, and upper.

6.2.6 Minimum dietary diversity (MDD-W)

The Food Agricultural Organization (FAO) diet quality questionnaire was used to assess the Minimum Dietary Diversity for Women (MDD-W) among the shellfishers (FAO, 2021a). It categorized foods into ten groups: pulses, nuts and seeds, dairy, grains, roots and tubers, eggs, dark leafy greens and vegetables, vitamin A-rich fruits and vegetables, meat, poultry, fish, other vegetables, and other fruits. To meet the minimum dietary diversity, women had to consume at least five of the ten food groups within a 24-hour period. The percentage of women aged 15–49 who achieved this minimum was used as an indicator of dietary quality and micronutrient intake (FAO, 2021a). The proportion of women meeting the MDD-W was calculated by dividing the number of women who consumed items from at least five food groups by the total number surveyed. This provided a population-level indicator for each estuarine site and the overall study. Individual scores also served as a continuous measure, allowing for the calculation of the mean MDD-W score across the sites and for the entire study population.

6.2.7 Food insecurity status

The Household Food Insecurity Access Scale (HFIAS) was used to assess household food insecurity. It included two sections: occurrence and frequency-of-occurrence questions, each with nine items. Positive responses to occurrence questions were coded as 1, and negative responses as

0. Frequency-of-occurrence was scored on a scale of 1 to 3 (Coates et al., 2007). The HFIAS evaluated anxiety, poor food quality, and inadequate food intake, summarizing how often households exhibited these behaviours. Household food insecurity was classified using the Household Food Insecurity Access Prevalence (HFIAP) indicator, which categorized households as mildly, moderately, or severely food insecure based on Food and Agricultural Organization guidelines (Coates et al., 2007). Mildly food insecure households worried about food and had limited food choices but did not reduce food quantity. Moderately food insecure households compromised food quality and occasionally reduced meal size. Severely food insecure households frequently faced severe conditions, such as running out of food, even if these conditions occurred rarely. The classification was based on the severity and frequency of food insecurity experienced in the past four weeks (Coates et al., 2007).

6.2.8 Anthropometry

Height was measured using a wooden mobile stadiometer (Priemyselna 4075, Slovakia) with a precision of 0.5 cm. Participants were instructed to stand with their feet together, and their heels, shoulder blades, and buttocks in contact with the stadiometer, following the procedure outlined by Cameron and Jones (2010). Weight was recorded using a Secca scale (22061 Hamburg, Germany) with a precision of 0.1 kg. Participants wore minimal clothing and emptied their pockets to ensure accurate measurements. These data were used to calculate Body Mass Index (BMI) according to World Health Organization (WHO, 2022) guidelines. Due to the small number of underweight participants, BMI categories were simplified into two groups: overweight/obese (≥ 25 kg/m^2) and not overweight/obese (≤ 24.9 kg/m^2).

6.2.9 Assessment of anaemia status

A capillary blood sample (0.2 ml) was collected from the index fingers of participants using a microcuvette and analysed on-site with a HemoCue 301 analyser (HemoCue AB, Sweden) to determine haemoglobin concentration. The haemoglobin levels were used to assess the prevalence of anaemia among women shellfishers. Anaemia was defined as haemoglobin levels below 12 g/dl, based on WHO guidelines for non-pregnant women (Addo et al., 2021; WHO, 2021b). The prevalence of anaemia was calculated as the proportion of women with haemoglobin levels below this threshold. Anaemic participants were further categorized as having mild (11–11.9 g/dl), moderate (8–10.9 g/dl), or severe anaemia (<8 g/dl) (Hu et al., 2019; USAID, 2022).

6.2.10 Statistical analyses

The participants' background characteristics were summarized using descriptive statistics, including means and percentages. The prevalence of overweight/obesity (BMI > 24.9 kg/m²) and anaemia (Hb < 12 g/dL) was calculated based on World Health Organization (WHO) thresholds (WHO, 2021b, 2022) and compared across sites using Pearson's Chi-Square test. Additionally, BMI and Hb levels were analysed across the three estuarine sites using analysis of covariance (ANCOVA). Two separate multiple logistic regression analyses were performed to identify factors associated with overweight/obesity and anaemia. Initially, unadjusted (crude) models were used to explore potential covariates with a significance threshold of $p < 0.2$. This threshold was chosen because relying on the conventional p-value cut-off of 0.05 when selecting covariates may overlook variables that are not independently significant but could become significant when included in a multivariable model (Malhotra, 2020). A high correlation between occupation and payment received in the past week ($r = 0.921$; $p < 0.001$) led to the inclusion of only occupation

in the final model due to its higher coefficient. The final multivariable models included covariates associated with overweight/obesity or anaemia at $p < 0.2$ in the crude models. Statistical significance for the final models was set at $p < 0.05$. All analyses were conducted using IBM SPSS Statistics (Version 27.0, Armonk, NY: IBM Corp.).

6.3 Results

6.3.1 Demographic and Socioeconomic factors of Women Shellfishers

Table 5.1 presents the demographic and socioeconomic characteristics of 504 women shellfishers surveyed across three estuarine sites in Ghana: Densu (200 participants), Narkwa (174 participants), and Whin (130 participants). The study achieved a high response rate of 91.3%. The average age of participants was 31.6 years (±9.1), with the majority falling within the 25–34 years (34%) and 35–44 years (32%) age groups. Educational attainment varied across the cohort, with 70% of women having ever attended school. However, only 39% had achieved at least secondary education, and the overall literacy rate was 45%. Notably, women from Densu had the highest schooling years (5.7 ± 3.8 years), whereas Narkwa reported the lowest (3.5 ± 3.5 years). Marital status showed 61% of the women were married, with Narkwa showing the highest proportion of married women (68%). Economic engagement was limited, as only 15% of respondents owned a small business, and just 8% were engaged in skilled labour. Densu had the highest rate of skilled labour participation (23%). Payment for work within the past week was received by 54% of participants, with the highest proportion reported in Whin (64%). Reproductive health indicators showed an average parity of 3.1 children (±2.3), with an average household size of 6.1 members (±2.5). Housing conditions revealed that 72% of households were constructed with cement, and 67% relied on charcoal as their primary cooking fuel. The average poverty rate across the sites was 13.2%, with Narkwa reporting the highest poverty incidence (23.0%). Regarding nutrition, 65%

of the women reported iron-folic acid (IFA) supplementation during their most recent pregnancy. Lactation was observed in 18% of the women, with the highest percentage reported in Narkwa (25%).

Table 5.1: Demographic and socioeconomic characteristics of women shellfishers from Densu, Narkwa, and Whin estuarine sites.

Variable	Estuarine Sites, N(%)			All sites=504
	Densu=200	Narkwa=174	Whin=130	
Age in completed years	32.2±8.5	30.8±9.4	31.9±9.7	31.6±9.1
≤ 24 years age group	44 (22)	48 (28)	33 (25)	125 (25)
25 - 34 years age group	73 (37)	59 (34)	38 (29)	170 (34)
35 - 44 years age group	66 (33)	53 (30)	42 (32)	161 (32)
≥ 45 years age group	17 (9)	14 (8)	17 (13)	48 (10)
Ever attended school	162 (81)	100 (57)	91 (70)	353 (70)
Attained at least secondary education	87 (44)	43 (25)	68 (52)	198 (39)
Schooling years[a]	5.7±3.8	3.5±3.5	5.6±4.3	4.9±4.0
Literacy rate	101 (51)	59 (34)	65 (50)	225 (45)
Married women shellfishers	125 (63)	119 (68)	65 (50)	309 (61)
Owned a small business[b]	39 (32)	18 (26)	17 (20)	74 (15)
Skilled labour[c]	28 (23)	4 (6)	9 (11)	41 (8)
Payment received in past week[d]	121 (61)	68 (39)	83 (64)	272 (54)
Parity of women shellfishers, births	2.6±1.8	3.6±2.6	3.2±2.3	3.1±2.3
Household size, members	5.5±2.3	6.5±2.2	6.5±3.1	6.1±2.5
Housing material is cement	114 (58)	141 (81)	106 (82)	361 (72)
Housing material is mud/mud/earth	34 (17)	13 (7)	19 (15)	66 (13)
Housing material is wood/bamboo/raffia	42 (21)	20 (11)	5 (4)	67 (13)
Household fuel is LPG	52 (26)	8 (5)	17 (13)	77 (15)
Household fuel is charcoal	136 (68)	121 (70)	83 (64)	340 (67)
Household fuel is wood	12 (6)	44 (25)	30 (23)	86 (17)
Household poverty rates[e]	7.2±9.2	23.0±16.4	9.2±9.5	13.2±14.2
IFA intake in recent pregnancy	131 (66)	101 (58)	95 (73)	327 (65)
Lactation	26 (13)	43 (25)	23 (18)	92 (18)

Values presented are means or proportions of participants contributing to the specific variables per estuarine site. [a]Include all the years participants spent schooling, counting from primary one as a complete academic year. [b]Includes participants operating provision shops, household table-top, and any form of established trading. [c]Includes all professions that required either formal or informal training. These include hairdressing, tailoring, etc. [d]Include both in kind and cash payment received from any work done by the participant. [e]Reflects the likelihood of household poverty, estimated from the poverty probability index (IPA, 2019).

6.3.2 Prevalence of overweight, obesity and anaemia

Table 5.2 presents the average BMI and Hb scores of women shellfishers across three estuarine sites. Significant variations in BMI were observed between the sites [$F(2, 225.7) = 9.5$; $p < 0.001$], controlling for maternal age, gravidity, number of children, household size, years of schooling, and household assets. The overall average BMI of women shellfishers was 24.9 ± 5.2 kg/m². Women from Densu had the highest average BMI (26.5 ± 5 kg/m²), followed by Whin (24.8 ± 5.2 kg/m²) and Narkwa (23.1 ± 4.9 kg/m²) ($p < 0.001$). Post hoc analysis revealed that Densu women had significantly higher BMI than those in Whin (3.44 kg/m², $p < 0.001$) and Narkwa (1.75 kg/m², $p = 0.006$). Women in Whin also had significantly higher BMI than those in Narkwa (1.69 kg/m², $p < 0.001$). The prevalence of underweight, overweight, and obesity among women shellfishers was 8.5%, 26.6%, and 17.1%, respectively, with overweight and obesity together accounting for 43.7% of the participants. Women in Densu had a significantly higher prevalence of overweight and obesity (58.3%) compared to Whin (43.1%) and Narkwa (27.6%) ($p < 0.001$). Obesity rates also varied significantly across the three sites: 23.1% in Densu, 14.4% in Narkwa, and 11.5% in Whin ($p < 0.014$). Similarly, the prevalence of underweight differed significantly: women in Narkwa had the highest prevalence (17.2%), followed by Whin (6.9%) and Densu (2.0%) ($p < 0.001$). For Hb scores, significant differences were found across sites [$F(2, 23.5) = 10.0$; $p < 0.001$], controlling for maternal age, years of schooling, number of children, household size, and assets. The overall mean haemoglobin (Hb) level was 12.9 ± 1.6 g/dl. Women from Whin had the highest Hb levels (13.4 ± 1.4 g/dl), significantly higher than those from Narkwa (12.9 ± 1.5 g/dl) and Densu (12.7 ± 1.7 g/dl) ($p < 0.001$). Multiple comparison tests showed that women from Whin had significantly higher Hb levels compared to Densu (Difference = 0.74 g/dl; $p < 0.001$) and Narkwa (Difference = 0.50 g/dl; $p = 0.019$). The overall prevalence of anaemia was 20%, with no

significant differences across the Densu, Narkwa, and Whin estuarine sites (25% vs. 20% vs. 15%; p = 0.068).

Table 5.2: Prevalence of overweight/obesity and anaemia among women shellfishers from Densu, Narkwa, and Whin estuarine sites.

Parameters	Estuarine sites, N (%)			P-value	All sites =504
	Densu=200	Narkwa=174	Whin=130		
BMI scores, kg/m^2	26.5±5^a	23.1±4.8^b	24.8±5.2^c	< 0.001	24.9±5.2
BMI categories					
Underweight [<18.5 kg/m^2]	4 (2.0)^a	30 (17.2)^b	9 (6.9)^c	<0.001	43 (8.5)
Overweight [18.5 – 29.9 kg/m^2]	70 (35.2)^a	23 (13.2)^b	41 (31.5)^c	<0.001	134 (26.6)
Obesity [≥30 kg/m^2]	46 (23.1)^a	25 (14.4)^b	15 (11.5)^c	0.014	86 (17.1)
Overweight/Obesity [≥ 25 kg/m^2]	116 (58.3)^a	48 (27.6)^b	56 (43.1)^c	<0.001	220 (43.7)
Not overweight/obesity [<25 kg/m^2]	83 (41.7)	127 (72.4)	74 (56.9)	-	284 (56.3)
Hb scores, g/dl	12.7±1.7^a	12.9±1.5^a	13.4±1.4^b	< 0.001	12.9±1.6
Hb categories					
Severe anaemia [<8 g/dl]	4 (2)	1 (1)	-	0.532	5 (1)
Moderate anaemia [8– 10.9 g/dl]	20 (10)	11 (6)	6 (5)	0.162	37 (7)
Mild anaemia [11– 11.9 g/dl]	26 (13)	22 (13)	13 (10)	0.692	61 (12)
Total anaemia [<12 g/dl]	50 (25)	34 (20)	19 (15)	0.068	103 (20)
Total non-anaemia [≥12 g/dl]	150 (75)	140 (80)	111 (85)	-	401 (80)

Differing superscripts (a, b, c) denote significant differences in nutrition status across the estuarine sites at a statistical significance set at p<0.05.

6.3.3 Factors associated with overweight/obesity

Table 5.3 presents the factors associated with overweight or obesity among women shellfishers. In the bivariate analysis, women from Densu (cOR = 1.85; 95% CI: 1.18–2.89) were nearly twice as likely to be overweight/obese compared to those from Whin, while women from Narkwa had 50% lower odds. Regular oyster consumption was associated with higher odds of overweight/obesity (cOR = 1.87; 95% CI: 1.10–3.19). Maternal age was also a significant factor;

women under 24 years had 80% lower odds compared to those over 45 years, though women aged 25–44 showed no significant difference. Being married increased the odds of overweight/obesity (cOR = 2.66; 95% CI: 1.71–4.12), as did working in skilled labour (cOR = 1.99; 95% CI: 1.02–3.89) or owning a business (cOR = 2.12; 95% CI: 1.26–3.59). Receiving payment lowered the odds by 40%, and a 3% decrease in the odds was observed with increased household poverty (aOR = 0.97; 95% CI: 0.95–0.98). Dietary patterns were not significantly associated with overweight/obesity. In the multiple regression analysis, women under 24 years remained significantly at lower risk of overweight/obesity (aOR = 0.27; 95% CI: 0.11–0.69) compared to those over 45 years. Marriage continued to increase the odds (aOR = 1.88; 95% CI: 1.07–3.30), while poverty remained protective (aOR = 0.98; 95% CI: 0.96–0.99). Women in the middle tertile of the nutrient-rich dietary pattern had higher odds of overweight/obesity (aOR = 1.68; 95% CI: 1.01–2.78) compared to those in the lower tertile.

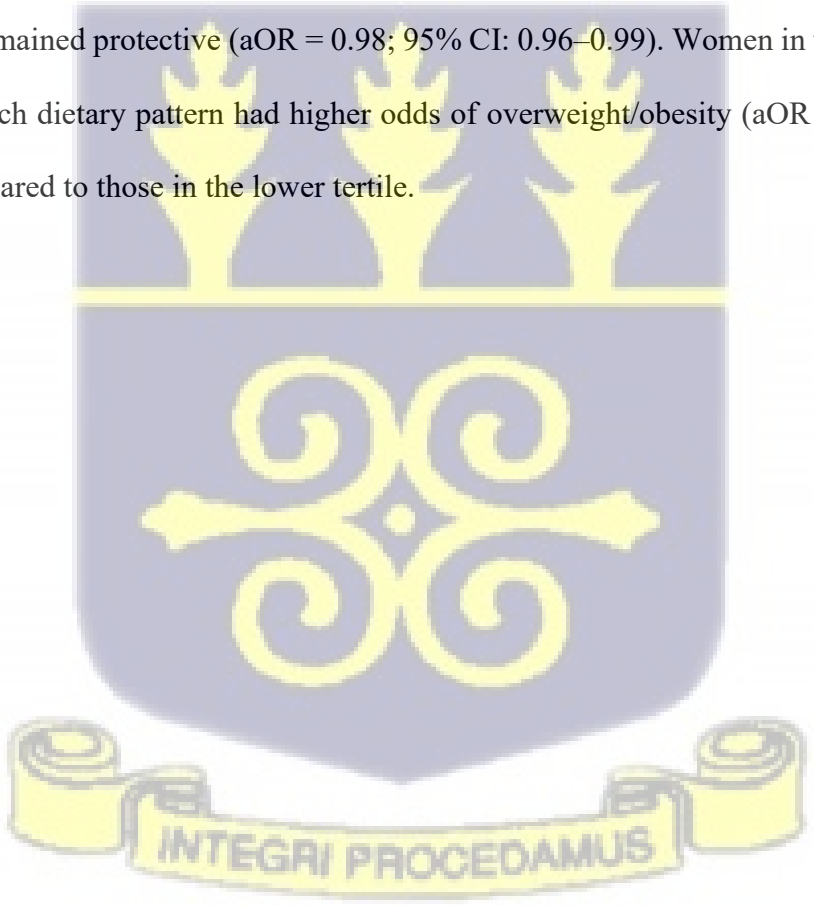

Table 5.3: Factors associated with overweight/obesity among women shellfishers from Densu, Narkwa, and Whin estuarine sites.

Variables	OR (95% Confidence Interval)			
	Crude model	Sig	Adjusted model	Sig
Estuarine sites, Ref = Whin	1.00			
Densu	1.85 (1.18, 2.89)	0.007	1.56 (0.92, 2.66)	0.103
Narkwa	0.49 (0.30, 0.79)	0.004	0.59 (0.33, 1.05)	0.073
Oyster intake	1.87 (1.10, 3.19)	0.021	1.59 (0.87, 2.90)	0.135
Age groups, Ref = 45+ years	1.00		1.00	
≤ 24 years	0.22 (0.11, 0.45)	<0.001	0.27 (0.11, 0.69)	0.006
25 - 34 years	0.81 (0.43, 1.54)	0.514	0.74 (0.35, 1.58)	0.432
35 - 44 years	0.94 (0.49, 1.79)	0.839	0.90 (0.44, 1.83)	0.762
Ever attended school	1.22 (0.83, 1.79)	0.315	-	
Literacy	1.14 (0.80, 1.62)	0.478	-	
Marital status				
Ref = Never married	1.00		1.00	
Married	2.66 (1.71, 4.12)	<0.001	1.88 (1.07, 3.30)	0.027
Previously married	2.08 (1.11, 3.91)	0.023	1.09 (0.51, 2.35)	0.828
Main Job, Ref = Not working	1.00		1.00	
Skilled labour	1.99 (1.02, 3.89)	0.044	1.10 (0.52, 2.34)	0.807
Unskilled labour	1.42 (0.94, 2.14)	0.101	1.13 (0.71, 1.81)	0.608
Owned a shop or business	2.12 (1.26, 3.59)	0.005	1.52 (0.83, 2.77)	0.176
Payment in past week (cash/kind)	0.61 (0.43, 0.87)	0.007	-	
Parity	1.11 (1.02, 1.20)	0.012	1.02 (0.90, 1.16)	0.716
Household size	1.00 (0.93, 1.07)	0.961	-	
Poverty rate	0.97 (0.95, 0.98)	<0.001	0.98 (0.96, 0.99)	0.011
Food insecurity status				
Ref = food secure	1.00		1.00	
Severely food insecure	0.72 (0.37, 1.38)	0.318	-	
Moderately food insecure	0.93 (0.41, 2.10)	0.863	-	
Mildly food insecure	1.40 (0.38, 5.16)	0.613	-	
Achieved MDD-W	1.29 (0.83, 2.0)	0.257	-	
Energy-dense Dietary pattern				
Ref = Lower	1.00			
Middle tertile	1.11 (0.68, 1.80)	0.673	-	
Upper tertile	1.21 (0.80, 1.83)	0.368	-	
Nutrient-rich dietary pattern				
Ref= Lower	1.00			
Middle tertile	1.41 (0.90, 2.22)	0.135	1.68 (1.01, 2.78)	0.046
Upper tertile	0.70 (0.46, 1.08)	0.105	0.96 (0.57, 1.61)	0.861

Reference category is overweight/obesity (BMI > 24.99 kg/m^2). *Analysis was statistically significant at $p < 0.05$

6.3.4 Factors associated with anaemia among women shellfishers

Table 5.4 presents the factors associated with anaemia among the study participants. In the bivariate logistic regression, estuarine sites emerged as significant determinants of anaemia. Women from the Densu site (cOR = 1.95; 95% CI: 1.09–3.49; p = 0.025) were nearly twice as likely to be anaemic compared to those from the Whin site. Age showed a weak, inverse association with anaemia (cOR = 0.98; 95% CI: 0.95-1.00; p = 0.052). Maternal BMI status was identified as a protective factor, with obese (cOR = 0.30; 95% CI: 0.14–0.66; p = 0.003) and overweight (cOR = 0.61; 95% CI: 0.36–1.04; p = 0.068) women having 70% and 40% lower odds of anaemia, respectively, although only obesity was significantly associated with reduced risk. In the multiple logistic regression, after adjusting for parity, age, marital status, and oyster consumption, estuarine site and maternal BMI remained significantly associated with anaemia. Women from Densu (aOR = 2.24; 95% CI: 1.20–4.18; p = 0.012) had more than twice the odds of being anaemic compared to those from Whin. Obese (aOR = 0.27; 95% CI: 0.12–0.61; p= 0.002) and overweight (aOR = 0.56; 95% CI: 0.32–0.98; p = 0.041) women had significantly lower odds of anaemia compared to women with normal BMI.

Table 5.4: Factors associated with anaemia among women shellfishers from Densu, Narkwa, and Whin estuarine sites.

Variables	OR (95% Confidence Interval)			
	Crude model	Sig	Adjusted model	Sig
Estuarine sites, Whin = Ref				
Densu	1.95 (1.09, 3.49)	0.025	2.24 (1.20, 4.18)	0.012
Narkwa	1.42 (0.77, 2.62)	0.264	1.26 (0.66, 2.41)	0.491
Oyster intake	1.50 (0.83, 2.79)	0.171	1.58 (0.83, 3.02)	0.168
Age, years	0.98 (0.95, 1.00)	0.052	0.99 (0.95, 1.02)	0.489
Ever attended school	0.74 (0.45, 1.22)	0.237	-	
Literacy	0.19 (0.59, 1.41)	0.684	-	
Currently married	1.37 (0.88, 2.12)	0.164	1.17 (0.71, 1.93)	0.531
Main Job, not working =Ref	1.00			
Skilled labour	1.14 (0.52, 2.48)	0.744		
Unskilled labour	0.65 (0.38, 1.10)	0.110		
Owned a shop or business	1.08 (0.58, 1.99)	0.813		
Paid in past week (cash/kind)	1.25 (0.81, 1.93)	0.310	-	
Parity, number	0.92 (0.83, 1.02)	0.100	1.01 (0.87, 1.18)	0.879
Household size	1.00 (0.92, 1.09)	0.971	-	
IFA intake in recent pregnancy	0.92 (0.54, 1.57)	0.750	-	
Currently lactating	0.91 (0.59, 1.41)	0.700	-	
Poverty rate	1.00 (0.99, 1.02)	0.683	-	
Food insecurity, Food secure = Ref	1.00			
Severely food insecure	1.48 (0.60, 3.64)	0.394	-	
Moderately food insecure	1.54 (0.53, 4.54)	0.438	-	
Mildly food insecure	1.89 (0.39, 9.07)	0.427	-	
Achieved MDD-W	0.74 (0.44, 1.23)	0.241	-	
BMI categories, Normal BMI = Ref	1.00		1.00	
Obese	0.30 (0.14, 0.66)	0.003	0.27 (0.12, 0.61)	0.002
Overweight	0.61 (0.36, 1.04)	0.068	0.56 (0.32, 0.98)	0.041
Underweight	1.01 (0.48, 2.12)	0.982	1.13 (0.51, 2.46)	0.767
Energy-dense dietary pattern				
Lower = Ref	1.00			
Middle tertile	1.41(0.78, 2.55)	0.257	-	
Upper tertile	1.21(0.72, 2.04)	0.480	-	
Nutrient-rich dietary pattern				
Lower = Ref	1.00			
Middle tertile	1.03 (0.59, 1.81)	0.909	-	
Upper tertile	1.07 (0.63, 1.80)	0.813	-	

Dependent variable is anaemia (Hb concentration <12 g/dl). Analysis was statistically significant at $p < 0.05$

6.4 Discussion

6.4.1 Prevalence of overweight/obesity in women shellfishers

The study compared anaemia and overweight/obesity rates among women shellfishers of reproductive age across estuarine sites and identified contributing factors. Significant variations in BMI and overweight/obesity rates were found, with nearly half of the women classified as overweight or obese. Densu had the highest rate (58.3%), followed by Whin (43.1%) and Narkwa (27.6%). These findings indicate a pressing public health concern related to overweight/obesity among women shellfishers in these regions. The high prevalence of overweight/obesity reflects a growing global trend, particularly in transitioning economies, where overweight/obesity has replaced undernutrition, especially among adult women (Ritchie & Roser, 2017; Swinburn et al., 2019; WHO, 2021a). Although the current study's overall overweight/obesity prevalence is about 10% lower than the global average for adult women reported by the WHO (2021a), it aligns with several global studies (Mitchell & Shaw, 2015; Ng et al., 2014) highlighting similar trends. This shift is commonly associated with lifestyle changes, such as reduced physical activity and increased caloric intake, often linked to urbanization and economic growth (Seydel et al., 2017). Overweight/obesity rates in this study are generally lower compared to high-income regions like the Americas and Europe (Chooi et al., 2019; Şahin & Borlu, 2022), but they align with similar trends in African countries such as Kenya, Zambia, and Zimbabwe (Amugsi et al., 2017; Mangemba & San Sebastian, 2020), where urbanization and nutrition transitions are progressing at comparable rates. Densu's higher prevalence is likely due to urbanization, which increases exposure to poor-quality diets and reduces physical activity, exacerbated by motorized transport and labour-saving technologies (Bose et al., 2022; Doku & Neupane, 2015; Lartey, 2021). Additionally, cultural factors likely play a role. In Ghanaian communities, sociocultural values

often associate favourably with larger body sizes among women (Appiah et al., 2016). These norms can reinforce positive perceptions of overweight and obesity, contributing to their rising prevalence. This combination of sociocultural preferences, economic conditions, and lifestyle changes offers a comprehensive explanation for the observed differences in overweight/obesity rates across the study sites, particularly the stark contrast between the more urbanized Densu and the less urbanized Whin and Narkwa estuarine sites.

6.4.2 Factors associated with overweight/obesity in women shellfishers

Overweight and obesity primarily result from an imbalance between caloric intake and energy expenditure (Caudwell et al., 2013). Prevention efforts should focus on promoting smaller portion sizes, low-energy-density foods, and increased physical activity, with attention to how these measures are shaped by sociodemographic and economic factors (Aryeetey et al., 2017). In this study, maternal age, marital status, dietary patterns, and poverty rate emerged as significant predictors of overweight and obesity among women shellfishers. However, oyster consumption and food insecurity were not significantly associated with overweight/obesity in the adjusted model. Maternal age above 45 years was a significant predictor of overweight and obesity, likely due to hormonal changes, such as decreased oestrogen, and lifestyle factors that reduce energy expenditure (Huang et al., 2020). This aligns with previous studies in Ghana (Doku & Neupane, 2015; Mbochi et al., 2012; Tuoyire et al., 2016). Older women tend to have lower physical activity due to supervisory roles at home and work (Aryee et al., 2013), contributing to weight gain. In contrast, younger women, particularly those under 24, benefit from faster metabolism and active lifestyles, lowering their obesity risk. Marriage was also a significant predictor, consistent with studies linking marital status to higher obesity risk (Agyemang et al., 2015; Doku & Neupane,

2015; Tuoyire et al., 2016). Married women may experience weight gain due to increased food security, cultural norms associating weight with prosperity, and dietary practices related to childbirth, such as overeating to support breastmilk production (Tuoyire et al., 2016). However, contrary findings from Agbeko et al. (2013) suggest this relationship may vary by context. A negative association between poverty and overweight/obesity was observed, consistent with evidence that wealthier women in low-income countries face higher obesity risks due to sedentary lifestyles and access to energy-dense foods (Lartey et al., 2019; Popkin & Ng, 2022).

Among shellfishers, physical labour and limited access to high-calorie foods likely reduce obesity risk. In contrast, in high-income countries like the U.S., poverty is associated with higher obesity risk due to reliance on cheap, calorie-dense foods (Hojjat & Hojatt, 2021). Overweight and obesity prevalence was higher in the more urbanized Densu site, likely due to access to processed foods and sedentary lifestyles (Doak & Popkin, 2017; Thapa et al., 2021). Rural areas, like Narkwa, had lower rates, possibly due to traditional diets and more physically active lifestyles. This urban-rural disparity is consistent with findings across African countries (Amugsi et al., 2017) but contrasts with patterns in the U.S., where rural areas have higher obesity rates (Trivedi et al., 2015). Furthermore, our study found a positive association between a nutrient-rich dietary pattern and obesity. This could be due to cultural emphasis on larger portions even though women may choose healthier pattern (Global Nutrition Report, 2021). The two dietary patterns identified in this study accounted for a relatively small proportion of the variation in the women's overall diets. This suggests that other unmeasured dietary factors or lifestyle behaviours could be contributing to obesity in this population. Especially, that the study found over 80% inadequate energy intake. The apparent contradiction between low daily energy intake and high prevalence of overweight and obesity (e.g., 58.3% at Densu) can be elucidated by the chronic versus acute nature of these

measures. Overweight and obesity are indicative of long-term energy imbalance and lifestyle factors, while the 24-hour dietary recalls capture short-term intake, specifically during Ghana's recovery from COVID-19 (June–December 2021), a period when food access and household income were still in a state of recovery. The temporarily reduced intake observed during this timeframe may not accurately reflect typical or historical consumption patterns. Furthermore, underreporting, particularly among overweight individuals, represents a well-documented limitation in dietary studies (Howes et al., 2024; Ravelli & Schoeller, 2020; Wehling & Lusher, 2019).

Prior exposure to an obesogenic environment, characterised by limited physical activity and a high consumption of calorie-dense, nutrient-poor foods, could account for weight gain prior to the study. Similar patterns have been documented in other low-income contexts, where food insecurity, poor diet quality, and metabolic adaptation contribute to the dual burden of undernutrition and obesity (FAO, 2021b). Consequently, the current low intake likely reflects recent hardship rather than the underlying causes of existing overweight and obesity.Further research is required to explore the complex relationship between dietary patterns and obesity in different cultural and socioeconomic contexts, as well as to assess how factors such as portion control and physical activity influence this dynamic. Contrary to expectations, food security was not significantly associated with obesity. This may be due to widespread food insecurity among the study population, obscuring potential associations. Although previous studies have linked food insecurity with obesity, especially in women (Morales & Berkowitz, 2016), this relationship did not emerge here.

6.4.3 Prevalence of anaemia in women shellfishers

Significant variations in haemoglobin (Hb) levels were observed between the Whin estuarine site and the other two sites, with anaemia affecting one in five women overall. The prevalence was highest in Densu (25%), followed by Narkwa (20%) and Whin (15%). Despite these relatively lower rates, anaemia remains a public health concern, particularly in Densu and Narkwa. These findings contrast with a previous study (Abreu et al., 2022) that reported much higher anaemia rates (72%–84%) in the same setting, likely due to differences in sample size. Our larger sample (200 participants) provides a more accurate estimate of anaemia prevalence compared to the smaller sample (66–70 participants) in the previous study. As smaller sample sizes often lead to less precise estimates and higher variability. The anaemia rate in this study (20%) is also lower than the global average of 30% (GNR, 2021; Stevens et al., 2022; WHO, 2023a) and aligns more closely with rates in the Americas (15.3%) and Europe (18.6%) (Knez et al., 2017; WHO, 2023b). In contrast, countries like Turkey and Haiti report higher rates (Mujica-Coopman et al., 2015; Saydam et al., 2017), and national rates in Asia and Africa are generally higher (Ali et al., 2020; Sappani et al., 2023; Sunuwar et al., 2020; WHO, 2023b). Variations in anaemia prevalence may be due to differences in diet, socio-demographics, and access to health services (Ansari et al., 2009; Rao et al., 2014). Women shellfishers, with greater access to iron-rich fish, likely have lower anaemia rates compared to women in the general population. The rates in this study are also lower than those reported in the Ghana Demographic and Health Survey (38.8%–46.7%) for women in coastal regions (GDHS, 2014, 2024) and align with more recent national surveys showing a decline in anaemia among women of reproductive age (Christian et al., 2022; Wegmüller et al., 2020).

6.4.4 Predictors of anaemia in women shellfishers

The significant factors associated with anaemia among women shellfishers were estuarine sites and BMI status. Anaemia remains a major public health issue for women of reproductive age, contributing to outcomes such as premature birth, low birth weight, and maternal mortality, and also affects cognitive development and productivity (Ali et al., 2020; WHO, 2023b). Nutritional deficiencies, shaped by socio-demographic and economic disparities, are key drivers of anaemia in women (Adu-Afarwuah et al., 2017; Merid et al., 2023; Teshale et al., 2020). Obesity and overweight were negatively associated with anaemia, consistent with previous studies in Ghana and other low- and middle-income countries (Armah-Ansah, 2023; Gautam et al., 2019; Merid et al., 2023; Petry et al., 2021; Woldu et al., 2020). However, this finding contrasts with research linking obesity to elevated hepcidin levels, which impair iron absorption and lower serum iron levels (Jones et al., 2017; Tussing-Humphreys et al., 2010). The finding may be explained by higher iron stores in overweight or obese women, despite elevated hepcidin levels, as reduced menstrual losses due to hormonal imbalances in obesity may contribute to higher serum iron levels (Hilton et al., 2023). Geographic disparities were evident, with women from Densu having twice the odds of anaemia compared to Whin, likely due to poor housing among migratory women (Agbekpornu et al., 2021) increasing parasite exposure, and degraded ecosystems affecting food security. This finding aligns with studies on geographic disparities in anaemia prevalence (Bhandari et al., 2016; Shitu & Terefe, 2022; Wegmüller et al., 2020). No significant association was found between dietary patterns and anaemia, likely due to limited dietary diversity. Although iron-rich foods were present in some diets, other factors such as bioavailability and consumption patterns may explain the lack of statistical significance (Hilton et al., 2023). Similarly, despite oysters being a good source of dietary iron, their consumption was low and unevenly distributed,

which could explain why no association was found between oyster intake and anaemia (Agbekpornu et al., 2021). The study found no significant association between household poverty and anaemia, a finding consistent with some previous studies (Gautam et al., 2019; Win & Ko, 2018). However, this contrasts with broader research indicating that wealth improves access to healthcare and nutrition, reducing anaemia risk (Armah-Ansah, 2023; Habyarimana et al., 2020; Sappani et al., 2023; Wegmüller et al., 2020). The uniform poverty rates across study sites may explain this outcome.

6.5 Strength and limitations

The study compared the prevalence of anaemia and overweight/obesity, as well as the associated factors, among women shellfishers of reproductive age. A key strength of this study is the use of a cross-sectional design, which enabled the collection of data from a large, diverse sample across three coastal regions in Ghana. This broad sampling enhances the generalizability of the findings to women shellfishers in Ghana. Additionally, the study addresses an under-researched population, providing valuable insights into the health status of women shellfishers, which can inform future public health interventions. However, the cross-sectional design limits the ability to infer causality between variables, as the relationships observed may not reflect temporal or causal links. Another limitation is the reliance on self-reported data, which introduces the potential for recall bias, particularly in areas such as dietary intake and physical activity, potentially affecting the accuracy of the results. Furthermore, the use of a 24-hour dietary recall over two non-consecutive days, rather than the recommended inclusion of one weekend day, may not fully capture habitual dietary patterns, limiting the ability to assess typical intake. A further limitation is the smaller-than-expected sample size from the Whin estuarine site, with only 84%

of the estimated participants available for recruitment. This shortfall could have reduced the statistical power of the study, potentially affecting the detection of significant associations in some models. Despite this, the study's statistical power is also influenced by other factors, such as effect size, significance level, and the number of predictors used in the models. These factors help provide valuable insights into the strength and precision of the observed associations, mitigating some concerns over sample size limitations.

6.6 Conclusion

In conclusion, this study highlights significant variations in the prevalence of anaemia, overweight, and obesity among women shellfishers across different estuarine sites in Ghana. The notably higher prevalence of overweight/obesity in Densu, exceeding the national average, contrasts with the comparatively lower rates observed in Narkwa and Whin. Conversely, the anaemia prevalence in these populations was significantly lower than the national average for women of reproductive age. These findings underscore the need for targeted public health interventions tailored to the specific health challenges faced by women in these communities. To address these issues, nutritional education programmes should be prioritized, focusing not only on the adoption of healthy dietary habits but also on non-dietary factors that contribute to anaemia, such as infections and reproductive health issues. In addition, integrating obesity prevention and management strategies into reproductive health services is crucial. This would ensure a holistic approach to women's health, addressing both undernutrition and overnutrition.

Contribution of Authors

Francis Z. Taabia: investigation, writing - original draft, visualization. Agartha N. Ohemeng: writing - review & editing, supervision. Seth Adu-Afarwuah: conceptualization, secured funding, writing - review & editing. Brietta M. Oaks: secured funding, writing - review & editing.

Declaration of interest

The authors assert that they have no conflict of interests or personal relationships that may have exerted any influence on the findings of this study.

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CHAPTER 7: Specific Objective Three

Dietary intake of calorie and micronutrients (iron and zinc) in women of reproductive age in three selected estuarine sites in Ghana: the contribution of oyster's consumption to mineral intake

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Abstract

Background: Micronutrient deficiencies are a significant public health concern for women, particularly affecting reproductive health. Oysters, rich in essential minerals, could help address local deficiencies. However, limited data exist on nutrient intake and inadequacies among women shellfishers involved in the oyster value chain. This study aimed to compare nutrient intakes and inadequacies among women shellfishers across three estuarine sites and evaluated oyster consumption's contribution to mineral intake.

Methods: In June and July 2021, dietary intake data from women of reproductive age at three estuarine sites were collected through two non-consecutive 24-hour dietary recalls. Nutrient intakes were estimated using the Ghana foods nutrient database and the West African Food Composition Table. ANOVA and Pearson's Chi Square were used to compare the mean intakes and percentage of inadequacies among women across the estuarine sites, respectively.

Results: The women's average daily caloric intake differed significantly across sites, with values of 1377kcal at Densu, 1470kcal at Whin, and 1592kcal at Narkwa Lagoon ($p = 0.011$). Iron intakes were similar across sites, with averages of 9.4mg at Densu, 9.1mg at Narkwa Lagoon, and 9.4mg at Whin ($p = 0.858$). Zinc intake also showed no significant variation, recorded at 6.4 mg for Densu, 5.6mg for Narkwa Lagoon, and 5.9mg for Whin ($p = 0.121$). Oyster consumption contributed 17.2% of the daily iron intake (1.6mg/day) and 18.3% of the daily zinc intake

(1.1mg/day). The prevalence of nutrient inadequacy, assessed across six nutrients was high and showed no significant variation among sites, with rates of 91.5% at Densu, 90.0% at Whin, and 94.8% at Narkwa Lagoon (p = 0.240).

Conclusion: Women shellfishers had inadequate nutrient intake, including zinc and iron. Despite relatively low consumption levels of oysters, they contributed approximately one-fifth of the overall zinc and iron intake of shellfishers. There is a pressing need for nutritional education initiatives aimed at promoting oyster consumption, thereby enhancing nutrient adequacy for women shellfishers and their households.

Keywords: dietary intakes, women, mineral inadequacy, calorie intake, and oysters.

7.1 Background

Micronutrient deficiencies represent a significant public health challenge, particularly for women of reproductive age. Deficiencies in essential minerals such as iron, calcium, and zinc have more pronounced effects on women due to their reproductive health demands (WHO, 2023b). Iron deficiency, a leading cause of anaemia, is associated with fatigue, weakened immune response, and pregnancy complications such as preterm delivery and low birth weight (WHO, 2023b; Young et al., 2023; Young et al., 2019). Similarly, zinc deficiency compromises immune function, increases infection susceptibility, and can lead to pregnancy and childbirth complications (Khan et al., 2022; National Institutes of Health (NIH), 2021). Both iron and zinc deficiencies impair cognitive function and productivity, making their mitigation critical for public health (National Institutes of Health (NIH), 2021; WHO, 2023b). Calcium deficiency, though less widely discussed, has been linked to premenstrual symptoms, hormonal imbalances affecting ovulation, and an

increased risk of preeclampsia during pregnancy (Bocchieri & Thys-Jacobs, 2008; Roth et al., 2018). Long-term calcium deficiency may also impact bone health and fertility (Zhu & Prince, 2012). Addressing these deficiencies is crucial for improving maternal and foetal health outcomes and enhancing women's overall well-being. Globally, approximately 30% of non-pregnant women and 38% of pregnant women suffer from anaemia, with iron deficiency accounting for around half of these cases (WHO, 2023b). This equates to 14.5% of non-pregnant and 19% of pregnant women globally affected by iron-deficiency anaemia (WHO, 2023b). Anaemia prevalence is particularly high in Africa (39.8%) and Southeast Asia (46.5%) (WHO, 2023b). Zinc deficiency, affecting an estimated 17.3% of the global population, is prevalent in regions such as South Asia and Sub-Saharan Africa, where rates approach 90% (Khan et al., 2022; Kumssa et al., 2015). In Ghana, anaemia has persisted as a public health issue for over three decades, currently affecting 41.1% of women aged 15–49 years (GDHS, 2024). Additionally, 15% of women in Ghana are zinc deficient, and 10% have both iron and zinc deficiencies (Gernand et al., 2019). Despite global efforts to address these issues, progress remains uneven, with many low- and middle-income countries, including Ghana, experiencing stagnation or increased prevalence of deficiencies (SWAC, 2019). These issues are exacerbated by poor dietary intake of essential nutrients, changes in traditional food systems, and shifts in dietary habits (GNR, 2021; Weerasekara et al., 2018; WHO, 2023a). Women living in coastal regions of Ghana depend on estuarine and mangrove-based shellfisheries for both food and income, with oyster harvesting playing a significant role in household livelihoods (Hayford, 2021; Janha et al., 2017b). Oysters, which are rich in micronutrients, particularly iron and zinc, are vital in addressing food insecurity and nutritional deficiencies in these communities (Abreu et al., 2020; Chuku et al., 2020; FAO, 2019). Shellfish such as oysters provide a readily available source of protein and other key nutrients (Taabia et al., 2023; Taylor et al., 2019; USDA,

2020a). However, little is known about the specific impact of oyster consumption on micronutrient intake among women involved in shellfish harvesting in West Africa. Given the potential of sustainable oyster harvesting to support nutrient intake, it is important to assess whether oysters serve as a primary source of iron and zinc for women shellfishers. This is especially pertinent as management practices, such as closed seasons, may affect availability and intake of micronutrients, potentially exacerbating deficiencies. Currently, no regional or national assessment exists on nutrient intake and inadequacies among shellfishers in Ghana. This study aimed to compare dietary intake and the prevalence of nutrient inadequacies among women of reproductive age in three estuarine sites in Ghana, with a particular focus on the contribution of oysters to overall mineral intake.

7.2 Methods

7.2.1 Study design, sites, and population

This cross-sectional study was conducted at three purposively selected estuarine sites in Ghana's coastal regions: Densu, Whin, and Narkwa Lagoons. The selection of these sites was based on the active participation of women in shellfish harvesting, their dependence on mangrove ecosystems for sustenance, and the biophysical conditions of the mangroves, including degradation levels and overall ecosystem health (Chuku et al., 2022). The Densu estuarine site is located in the Ga South District of the Greater Accra Region, spans approximately 5,892 hectares (Janha et al., 2017a). The site includes the communities of Bortianor, Tettegu, and Tsokomey, with a combined population of 34,453, primarily composed of Ga and Ewe (Danso, 2013; GSS, 2014c; Janha et al., 2017a). The residents rely heavily on fishing and vegetable farming, with an annual mangrove oyster yield of 8,816 kg per person (GSS, 2014c; Janha et al., 2017a). The community benefits from regulated oyster harvesting and aquaculture experiments aimed at enhancing oyster

populations. Narkwa Lagoon is situated in the Central Region, surrounds the Ekumfi Narkwa community to the south and is fed by tributaries of the Okye River. This 110-hectare site features mangrove vegetation and is economically sustained by artisanal marine fishing and shellfish trade, particularly important for women in the area. The annual oyster yield from the lagoon is estimated at 9,512 kg per person (Osei et al., 2021b). The community of Ekumfi Narkwa, with a population of 4,634, also benefits from salt production and a tourist centre (Global Brigades, 2022). The Whin estuary, located in the Ahanta West District of the Western Region, lies near New Amanful, close to Takoradi Airport. It supports the communities of Beahu, Apremdo, and New Amanful, with a total population of 20,009 (GSS, 2014a, 2014b). Unlike other estuaries, the Whin estuary boasts healthy mangrove vegetation, providing crucial ecological protection. The site has a seasonal oyster yield of approximately 6,960 kg per person, making it a significant source of income for local women, second only to the Volta estuary (Osei et al., 2021b). Ethical approval for the study was granted by the Ethics Review Committee of the Ghana Health Service (GHS-ERC 015/l2/20). Written consent was obtained from local authorities, including traditional chiefs, local assembly representatives, and members of the Oyster Pickers' Associations at each site. Informed consent or assent was also obtained from all participants. Data collection occurred during the COVID-19 pandemic, with strict adherence to public health protocols, including the provision of personal protective equipment, social distancing, and frequent handwashing, to minimise transmission risks.

The study targeted women along the oyster value chain across three purposively selected estuarine sites. A sample size of 552 participants was determined to detect a moderate effect size (0.3) in mean blood haemoglobin concentrations across the three sites. This calculation, based on a two-sided 5% significance level and 80% power, required a target of 184 participants per site.

Participants were women aged 15 to 49, residing in communities surrounding the Densu, Whin, and Narkwa estuaries. Eligible women were engaged in activities related to the oyster value chain, including harvesting, processing, and selling. To qualify for the study, participants needed to have lived in the selected communities for at least six months before data collection. Women who declined to provide consent or those who verbally disclosed pregnancy at the time of recruitment were excluded from the study. Local guides and women's group leaders assisted in the data collection process, identifying eligible participants based on the inclusion criteria. Random selection from the sampling frame was facilitated using the R software package (R Development Core Team, 2005), ensuring an unbiased representation of the women shellfishers in each community.

7.2.2 Background characteristics

A structured questionnaire was employed to gather maternal data for the study. This encompassed sociodemographic information, including age, marital status, educational attainment, literacy, and occupation, as well as household factors such as household size, asset ownership, and poverty status. The questionnaire also integrated the FAO's standardised tools for assessing food security and minimum dietary diversity (Coates et al., 2007), in addition to inquiries regarding oyster consumption.

7.2.3 Assessment dietary intakes

Dietary intake data were collected using two non-consecutive 24-hour dietary recalls, conducted by trained field assistants in participants' households. The United States Department of Agriculture (USDA) Multiple-Pass Method was employed to enhance the accuracy and completeness of the dietary information collected (Raper et al., 2004). This method consists of five steps: (1) a quick

list of foods consumed, (2) a probe for forgotten foods, (3) time and occasion of food consumption, (4) detailed descriptions of foods and beverages, and (5) a final review to ensure completeness. Data collection took place from June to July 2021, with interviews conducted on all days of the week to capture variation in dietary habits. Participants were assisted in estimating portion sizes using common household measures, such as cups, ladles, and spoons, as well as locally improvised models for foods like fish, bread, sausage, orange, and corn. The reported portion sizes were converted into grams and analysed using the Ghana Foods Nutrient Database (GFND), developed by the Department of Food Science and Nutrition at the University of Ghana (Armah et al., 2012). For food items not listed in the GFND, nutrient composition was estimated using the USDA Food Composition Table and the West African Food Composition Table (USDA, 2020a; Vincent et al., 2020). The mean energy and mineral intake from the two non-consecutive recall days was used to estimate the participants' usual intake in this study (Meyers et al., 2006).

7.2.4 Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows (Version 27.0, Armonk, NY: IBM Corp). Descriptive statistics, including means and percentages, were used to summarise the sociodemographic characteristics of the participants, such as age, education, parity, occupation, and poverty rates. Usual dietary energy and mineral intakes, including iron and zinc derived from oyster consumption, were presented as means and standard deviations based on the two non-consecutive 24-hour dietary recalls. The average intake of iron and zinc from oyster consumption was further expressed as a proportion of each participant's total usual intake. The Acceptable Macronutrient Distribution Range (AMDR) guidelines from the Institute of Medicine were used to assess macronutrient distribution, with carbohydrates expected to contribute 45–65%, fats 20–35%, and proteins 10–35% of the recommended daily intake of 2,000 kcal for women aged

18 to 50 years (Meyers et al., 2006). The Nutrient Adequacy Ratio (NAR) was calculated as the ratio of a participant's nutrient intake to the Recommended Dietary Allowance (RDA) for each nutrient. A NAR of 1 or greater indicated adequate intake, whereas a value below 1 signified inadequate intake. The Mean Adequacy Ratio (MAR) was determined by averaging the NARs for six essential minerals: zinc, iron, calcium, phosphorus, potassium, and magnesium. The proportion of women with inadequate nutrient intakes (NAR < 1) was calculated to determine the prevalence of nutrient inadequacies for each mineral. Additionally, the proportion of women demonstrating a MAR of less than 1 was used to indicate the prevalence of inadequacy across the six nutrients. These proportions were compared across the study sites using chi-square tests. Analysis of variance (ANOVA) was employed to compare dietary intakes and the nutrient adequacy ratios across the three selected estuarine sites. Statistical significance in all analyses was determined at $p < 0.05$.

7.3 Results

7.3.1 Background characteristics of participants

Table 6.1 summarizes the socioeconomic and demographic characteristics of the women shellfishers. The mean age was 31.6 ± 9.1 years, with most women aged 25–34 in the Narkwa and Densu sites and 35–44 in the Whin site. Educational attainment varied, with over 80% of women from Densu receiving some education, but fewer than half completing secondary school. In Whin, 52% had secondary education, compared to 25% in Narkwa. Literacy rates were highest in Whin and Densu, where approximately half the women were literate. Marital status showed that 50% of women in Whin, 63% in Densu, and 68% in Narkwa were married. Employment was more common in the Whin and Densu sites, with slightly over half of the women reporting paid work in the past week. Household size was similar across the sites, with women from Narkwa and Whin

having an average of seven household members, and those from Densu having six. Narkwa had the highest parity (3.6), compared to 2.6 in Densu. Cement was the primary housing material (58–82%), and charcoal was the main domestic fuel (64–70%). Poverty rates ranged from 7.2% in Densu to 23% in Narkwa. Women owned an average of two household assets. At the time of the study, 18% of the women were lactating, while 58–73% took iron and folic acid supplements during their most recent pregnancies, and 35–50% took vitamin A.

Table 6.1: Background characteristics of women shellfishers of 15-49 years of age across selected estuarine sites along the coast of Ghana

Variable	Estuarine Sites N (%)			All sites = 504
	Narkwa = 174	Whin = 130	Densu = 200	
Age in completed years	30.8±9.4	31.9±9.7	32.2±8.5	31.6±9.1
≤ 24 years age group	48 (28)	33 (25)	44 (22)	125 (25)
25 - 34 years age group	59 (34)	38 (29)	73 (37)	170 (34)
35 -44 years age group	53 (30)	42 (32)	66 (33)	161 (32)
≥ 45 years age group	14 (8)	17 (13)	17 (9)	48 (10)
Ever attended school	100 (57)	91 (70)	162 (81)	353 (70)
School life expectancy[a]	3.5±3.5	5.6±4.3	5.7 ± 3.8	4.9 ± 4.0
Literacy rate	59 (34)	65 (50)	101 (51)	225 (45)
Married women shellfishers	119 (68)	65 (50)	125 (63)	309 (61)
Owned a small business[b]	18 (26)	17 (20)	39 (32)	74 (15)
Skilled labour[c]	4 (6)	9 (11)	28 (23)	41 (8)
Worked in past week for cash or in-kind payment[d]	68 (39)	83 (64)	121 (61)	272 (54)
Parity of women shellfishers	3.6±2.6	3.2±2.3	2.6±1.8	3.1±2.3
Household size	6.5±2.2	6.5±3.1	5.5±2.3	6.1±2.5
Poverty rates[e]	23.0±16.4	9.2±9.5	7.2±9.2	13.2±14.2
Household asset score (out of six HH assets)	1.3±1.5	2.3±1.7	3.4±1.8	2.0±1.8
IFA intake in recent pregnancy	101 (58)	95 (73)	131 (66)	327 (65)
Vitamin A intake in recent pregnancy	61 (35)	65 (50)	80 (40)	206 (41)
Lactation	43 (25)	23 (18)	26 (13)	92 (18)

Values presented are means or proportions of participants contributing to the specific variables per estuarine site.
[a]Include all the years participants spent schooling, counting from primary one as a complete academic year.
[b]Includes participants operating provision shops, household table-top, and any form of established trading.
[c]Includes all professions that required either formal or informal training. These include hairdressing, tailoring, etc.
[d]Include both in kind and cash payment received from any work done by the participant.
[e]Reflects the likelihood of household poverty, estimated from the poverty probability index (IPA, 2019).

7.3.2 Dietary calorie, micronutrient intakes of women shellfishers and contributions of oyster consumption to iron and zinc intakes.

Table 6.2 presents the dietary intake of macronutrients and micronutrients among women shellfishers across the three estuarine sites. Average calorie intake ranged from 1,377.2 ± 533.3 kcal/day in Densu to 1,592.2 ± 846.6 kcal/day in Whin, with a significant difference observed across sites ($P = 0.011$). Protein intake was significantly higher in Whin (44.3 ± 27.9 g/day) compared to Densu and Narkwa ($P = 0.031$). Fat intake also varied significantly, with the highest intake recorded in Whin (57.5 ± 40.3 g/day; $P < 0.001$), whereas carbohydrate, fibre, and monounsaturated fat (MUFA) intake exhibited no significant differences between sites. Total iron (Fe) intake across all sites was 9.3 ± 5.8 mg/day, with no significant differences observed between sites ($P = 0.858$). Oyster-derived iron intake was highest in Densu (2.9 ± 9.6 mg/day; $P < 0.001$), contributing 17.2% to the total iron intake across all sites. Total zinc (Zn) intake was 6.0 ± 3.9 mg/day, with no significant differences detected across sites ($P = 0.121$). Similarly, oyster-derived zinc intake was also highest in Densu (1.9 ± 6.3 mg/day; $P < 0.001$), contributing 18.3% of the total zinc intake. Overall, the proportion of women reporting oyster consumption based on the 24-hour recall was 12.5%, with the highest proportion recorded in Densu (19%). Variability in micronutrient intake was noted for potassium, with Whin exhibiting the highest intake (2055.0 ± 1170.5 mg/day; $P < 0.001$), while phosphorus and magnesium intake displayed significant differences across sites ($P < 0.001$ and $P = 0.013$, respectively).

The dietary components of total calorie intake among women of reproductive age across selected estuarine sites exhibited notable variations (Table 6.3). Carbohydrates, serving as a primary energy source, demonstrated significant variation across the sites, comprising 65% of total calorie intake at Densu, 60% at Narkwa, and 59% at Whin ($p < 0.001$), with all sites falling within the recommended range of 45-65%. Protein intake remained relatively consistent across the sites,

contributing approximately 11% of total caloric intake, which was in close proximity to the recommended 10%. Sugar intake also displayed significant variation, contributing 10%, 8%, and 9% at Densu, Narkwa, and Whin, respectively ($p < 0.001$). Fat intake revealed considerable variation, with contributions of 27%, 32%, and 33% at Densu, Narkwa, and Whin, respectively ($p < 0.001$), all of which fell within the recommended range of 20-35%. Among fatty acids, saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) contributed similarly, accounting for approximately 9% across all sites without significant differences. In contrast, polyunsaturated fatty acid (PUFA) intake varied, with the lowest observed at Narkwa (4%) and slightly higher levels at Densu and Whin (5%) ($p < 0.001$).

Table 6.2: Macronutrient and micronutrient intakes of women shellfishers and contributions of oyster consumption to iron and zinc intakes.

Nutrients	Densu	Narkwa	Whin	P-value	All sites
Macronutrients					
Calories, kcal	1377.2 ± 533.3[b]	1469.6 ± 626.7[b, c]	1592.2 ± 846.6[c]	0.011	1464.5 ± 662.0
Protein, g/d	37.7 ± 18.6[b]	39.4 ± 23.6[b, c]	44.3 ± 27.9[c]	0.031	40.0 ± 23.1
Carbohydrate, g/d	223.6 ± 83.1[a]	221 ± 94.8[a]	234.5 ± 118.7[a]	0.462	225.5 ± 97.3
Fibre, g/d	17.4 ± 7.0[a]	17.2 ± 7.7[a]	17.7 ± 9.4[a]	0.889	17.4 ± 7.9
Sugar, g/d	34.2 ± 20.1[a]	28.1 ± 22.0[b]	36.0 ± 29.0[a]	0.007	32.6 ± 23.5
Fat, g/d	40.8 ± 22.2[a]	51.6 ± 27.7[b]	57.5 ± 40.3[c]	<0.001	48.8 ± 30.4
SFA, g/d	13.5 ± 9.0[a]	13.3 ± 10.0[a, b]	16.1 ± 16.9[c]	0.073	14.1 ± 11.9
MUFA, g/d	14.5 ± 8.7[a]	14.3 ± 9.5[a]	16.5 ± 14.5[a]	0.160	15.0 ± 10.7
PUFA, g/d	8.1 ± 4.3[a]	7.1 ± 4.3[b]	7.9 ± 6.1[a, b]	0.130	7.7 ± 4.9
Cholesterol, g/d	106.1 ± 130.8[a]	66.4 ± 75.8[b]	128.9 ± 153.4[a]	<0.001	98.3 ± 124.1
Oyster intake, grams/day	16.7[a]	5.2[b]	0.4[b]	</0.001	8.6
Oyster intake, (% women from 24-hr recall)	19.0	13.2	1.5	-	12.5
Micronutrients					
Na, mg/d	2640.6 ± 1220.0[a]	2461.7 ± 1159.8[a]	2557.6 ± 1369.2[a]	0.380	2557.4 ± 1240.3
K, mg/d	1619.7 ± 703.7[a]	1796.2 ± 872.0[a]	2055.0 ± 1170.5[c]	<0.001	1792.9 ± 915.7
P, mg/d	800.8 ± 341.9[a]	655.7 ± 320.0[b]	727.6 ± 442.5[a, b]	<0.001	731.8 ± 368.2
Mg, mg/d	265.4 ± 110.7[a]	229.2 ± 109.3[b, c]	247.7 ± 139.6[a, c]	0.013	248.4 ± 119.1
Ca, mg/d	235.4 ± 166.5[a]	214.6 ± 131.2[a, b]	266.2 ± 266.6[a, c]	0.061	236.2 ± 188.4
Fe, mg/d	9.4 ± 6.2[a]	9.1 ± 5.4[a]	9.4 ± 5.7[a]	0.858	9.3 ± 5.8
Fe (oyster intake), mg/d	2.9 ± 9.6[a]	1.3 ± 3.6[b, c]	0.1 ± 0.6[c]	<0.001	1.6 ± 6.5
Fe (oyster intake), % of total Fe intake	30.9	14.3	1.2	-	17.2
Zn, mg/d	6.4 ± 4.2[a]	5.6 ± 3.5[b]	5.9 ± 4.0[a, b]	0.121	6.0 ± 3.9
Zn (oyster intake), mg/d	1.9 ± 6.3[a]	0.8 ± 2.4[b]	0.05 ± 0.4[c, b]	</0.001	1.1 ± 4.2
Zn (oyster intake), % of total Zn intake	29.7	14.3	0.8	-	18.3

Each subscript letter (a, b, or c) denotes a subset of dietary energy and minerals intakes, the contribution from oyster consumption to iron and zinc intakes whose column mean do not differ significantly from each other at the .05 level. ANCOVA with Tukey-Kramer's test were performed to test for significant differences between sites while controlling for the age of the women.

Table 6.3: Amount and percentage contribution of macronutrients to the total calorie intake in women of reproductive age across selected estuarine sites.

Nutrients/Sites	IOM RDA	Densu	Narkwa	Whin	P-value	All sites
		Mean (% DI)	Mean (% DI)	Mean (% DI)		Mean (% DI)
Protein, kcal	200 (10%)	151 ± 75 (11)	158 ± 95 (11)	177 ± 111 (11)	0.223	160 ± 93 (11)
Carbohydrate, kcal	900-1,300 (45-65%)	894 ± 332 (65)[a]	879 ± 384 (60)[b]	938 ± 475 (59)[c]	<0.001	900 ± 391 (62)
Sugar, kcal	200 (10-35%)	137 ± 80 (10) [a]	113 ± 88 (8)[b]	144 ± 116 (9)[c]	<0.001	130 ± 94 (9)
Fat, kcal	400-700 (20-35%)	367 ± 200 (27) [a]	465 ± 249 (32)[b]	517 ± 363 (33)[c]	<0.001	440 ± 274 (30)
SFA, kcal	200 (<10%)	121 ± 81 (9)	119 ± 90 (8)	145 ± 152 (9)	0.603	127 ± 107 (9)
MUFA, kcal	-	131 ± 78 (9)	129 ± 85 (9)	149 ± 131 (9)	0.480	135 ± 97 (9)
PUFA, kcal	-	73 ± 39 (5)[a]	64 ± 39 (4)[b]	71 ± 55 (5)[c]	<0.001	70 ± 44 (5)

Differing subscripts (a, b, or c) indicate contribution (proportions) of the dietary components to the total intake differ significantly from each other at the .05 level.

7.3.3 Nutrient adequacy ratios and prevalence of inadequacy among women shellfishers across estuarine sites.

Table 6.4 provides a comparative analysis of nutrient adequacy ratios, mean adequacy ratios (MAR), and the prevalence of women below the nutrient and mean adequacy ratios among the women shellfishers (ages 15–49) from three estuarine sites: Densu, Narkwa, and Whin. Significant site-specific differences were observed for caloric, calcium, phosphorus, and potassium intake inadequacies. Caloric inadequacy was most prevalent in Whin (73.8%), followed by Narkwa (78.7%) and Densu (89.0%), with an overall rate of 81.5% across all sites ($p = 0.001$). Calcium inadequacy was highest in Narkwa (100%), slightly lower in Densu (99.5%), and lowest in Whin (96.9%), demonstrating notable site-based disparities ($p = 0.022$). Phosphorus inadequacy also varied significantly, being lowest in Densu (40.5%) and higher in Narkwa (60.9%) and Whin (61.5%) ($p < 0.001$). Potassium intake inadequacy showed a similar pattern, with the lowest prevalence in Whin (96.2%), a slight increase in Narkwa (99.4%), and the highest in Densu (100%) ($p = 0.004$). However, the inadequacies in zinc, iron, and magnesium intake were consistent across the sites, indicating relatively uniform nutrient intake for these elements. The MAR, an aggregate measure of adequacy across six nutrients, indicated marginally higher inadequacy in Narkwa (94.8%) compared to Densu (91.5%) and Whin (90.0%), although this variation was not statistically significant ($p = 0.240$). Overall, the findings reveal substantial site-specific disparities in the inadequacies of caloric, calcium, phosphorus, and potassium intake among the women shellfishers.

Table 6.4: Average nutrient adequacy ratios, mean adequacy ratios and proportions of Ghanian women shellfishers (ages 15-49) with nutrient intakes below the Recommended Dietary Allowance (RDA) from selected the estuarine sites.

Nutrients	Densu	Narkwa	Whin	P-value	All sites
	Mean (%<RDA)	Mean (%<RDA)	Mean (%<RDA)		Mean (%<RDA)
Calorie	0.69 ± 0.27 (89.0[a])	0.73 ± 0.31(78.7)[b]	0.80 ± 0.42 (73.8)[c]	0.001	0.73 ± 0.33 (81.5)
Zinc	0.80 ± 0.52 (74.5)	0.70 ± 0.44 (77.0)	0.73 ± 0.49 (77.7)	0.773	0.75 ± 0.49 (76.2)
Iron	0.52 ± 0.34 (94.0)	0.50 ± 0.30 (94.3)	0.52 ± 0.31 (93.8)	0.999	0.52 ± 0.32 (94.0)
Calcium	0.24 ± 0.17 (99.5)[a]	0.21 ± 0.13 (100)[b]	0.27 ± 0.27 (96.9)[c]	0.022	0.24 ± 0.19 (99.0)
Phosphorus	1.14 ± 0.49 (40.5)[a]	0.94 ± 0.46 (60.9)[b]	1.04 ± 0.63 (61.5)[c]	<0.001	1.05 ± 0.53 (53.0)
Potassium	0.34 ± 0.15 (100)[a]	0.38 ± 0.19 (99.4)[b]	0.44 ± 0.25 (96.2)[c]	0.004	0.38 ± 0.19 (98.8)
Magnesium	0.84 ± 0.37 (70.5)	0.73 ± 0.33 (77.0)	0.79 ± 0.44 (78.5)	0.186	0.79 ± 0.38 (74.8)
MAR*	0.65 ± 0.27 (91.5)	0.58 ± 0.24 (94.8)	0.63 ± 0.30 (90.0)	0.240	0.62 ± 0.27 (92.3)

Differing subscript letters (a, b, and c) indicate proportions of women below the nutrient and mean adequacy ratios differ significantly among women shellfishers across estuarine sites at the 0.05 significance level. RDA mean recommended dietary allowance. *MAR indicates mean adequacy ratio, derived based on six nutrients (zinc, iron, calcium, phosphorus, potassium, and magnesium).

7.4 Discussion

This study compared the dietary intake of calories and micronutrients, particularly iron and zinc, among women of reproductive age involved in shellfish harvesting, with a focus on the contribution of oyster consumption to total mineral intake. The findings revealed that women met only 73.2% of the recommended dietary energy intake (2,000 kcal/day), with 81.5% experiencing inadequate energy intake. The average intake of 1,464.5 kcal/day was significantly lower than that reported for black women in the United States (Ladabaum et al., 2014) and in Asian countries such as Vietnam and Bangladesh (Islam et al., 2020; Nguyen et al., 2013). This is consistent with findings from rural India and Thailand, where women of reproductive age similarly fail to meet

energy requirements (Puwanant et al., 2022; Sharma et al., 2020). The results align with earlier reports of inadequate energy intake among women in coastal Ghana (Kobati et al., 2012), though the current study shows even lower intake levels, likely due to the compounded effects of food insecurity and the economic aftermath of the COVID-19 pandemic (Adusei, 2021). Interestingly, the women's macronutrient distribution closely matched the recommended proportions for carbohydrates (58.9–64.9%), fats (26.6–32.5%), and proteins (10.7–11.1%) (Manore, 2005). The high fat intake observed in this study, while still within recommended limits, contrasts with lower fat intake reported in other studies from (Islam et al., 2020; Nguyen et al., 2013; Sharma et al., 2020). This discrepancy may be attributed to differences in food sources, particularly seafood and local dietary patterns. These results reinforce the need to focus on both overall calorie intake and nutrient quality when addressing nutritional deficiencies among women in coastal communities. A key finding of this study is the widespread inadequacy of micronutrient intake, particularly iron and zinc. Iron intake was notably below the recommended dietary allowance, with 94% of women failing to meet the RDA. The mean iron intake range (7.6–10.7 mg/day) across the three site is comparable to reported levels in several European countries (Knez et al., 2017; Lim et al., 2015; Milman, 2019; Vaesken et al., 2017) but lower than those in Germany, France, and the US (Milman, 2019; NIH, 2021b). Similarly, zinc intake was inadequate in 96.2% of women, with a mean adequacy ratio of 0.75. The zinc intake in this study is slightly higher than that reported for Indian women (4.8–5.5 mg/day) (Nunn et al., 2019; Sharma et al., 2020) but lower than intakes observed in Europe (7.3–9.3 mg/day) (Knez et al., 2017; Lim et al., 2015; Milman, 2019; Vaesken et al., 2017) and the US (9.2 mg/day) (NIH, 2021b). The widespread inadequacies in iron and zinc observed in this study are concerning, as both micronutrients are essential for immune function, cognitive health, and reproductive outcomes. These findings are consistent with studies from

Africa, where iron and zinc deficiencies are prevalent (Harika et al., 2017; Kaliwile et al., 2019). The high prevalence of iron and zinc inadequacies among these women underscores their vulnerability to iron deficiency anaemia and the associated risks of impaired immune function and reduced work productivity. Oyster consumption was found to play a significant role in nutrient intake, particularly contributing to iron and zinc levels, accounting for about one-fifth of total intake. Women who consumed oysters had higher average intakes of iron (15 vs 9 mg/day) and zinc (10 vs 5 mg/day) compared to non-consumers. This underscores the potential of shellfish as an important dietary source for addressing micronutrient deficiencies in coastal communities. However, despite the benefits of oyster consumption, the majority of women still failed to meet the Recommended Daily Allowance (RDA) for these critical minerals, indicating that oysters alone may not be sufficient to fully bridge the nutrient gap. Additionally, the study revealed a low prevalence of oyster consumption among women, attributed to economic benefits from its sale (Agbekpornu et al., 2021). The study also revealed that nutrient intake was influenced by food security status and dietary diversity. Women from food-secure households and those with higher dietary diversity scores had better nutrient adequacy ratios, further demonstrating a wholistic approach toward nutritional health. This aligns with other research showing the critical role of food access and dietary diversity in improving micronutrient intake (Harika et al., 2017; Kaliwile et al., 2019). Overall, the findings of this study underscore the challenge of undernutrition among women shellfishers in Ghana. The high rates of inadequacies in energy, iron, and zinc intake have significant implications for maternal and reproductive health, particularly in these estuarine sites where food insecurity is prevalent. Addressing these deficiencies will require not only increasing access to nutrient-rich foods like oysters but also improving overall food security and dietary diversity.

7.5 Conclusion

This study elucidates the inadequate dietary intake of calories and essential micronutrients, specifically iron and zinc, among women of reproductive age engaged in oyster value chain in coastal Ghana. While oysters contributed to mineral intake, they were insufficient to meet the recommended levels for these critical nutrients. Furthermore, the women consumed only two-thirds of the recommended daily calorie intake, highlighting the broader issue of food insecurity. These findings underscore the necessity for comprehensive nutritional interventions that promote dietary diversity, enhance food security, and address the factors influencing nutrient absorption to improve maternal nutrition and reproductive health outcomes within these estuarine sites.

Contribution of Authors

Francis Z. Taabia: investigation, writing - original draft, visualization. Agartha N. Ohemeng: writing - review & editing, supervision. Seth Adu-Afarwuah: conceptualization, secured funding, writing - review & editing. Brietta M. Oaks: secured funding, writing - review & editing.

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Declaration of interest

The authors assert no conflict of interests or personal relationships that may have exerted any influence on the findings of this study.

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CHAPTER 8: Specific Objective Four

Dietary Mineral Concentrations in Oysters and Adverse Health Risk Assessment among Women Shellfishers in Three Selected Estuarine Sites in Ghana

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Abstract

Background: Oysters are rich in essential minerals, but their nutrient content varies by geography and species. They may also pose health risks due to heavy metal contamination. This study aimed to compare mineral levels in oysters from estuarine sites and assess whether the observed heavy metal concentrations present public health risks.

Methods: In June and July 2021, 915 mangrove oyster (*Crassostrea tulipa*) specimens were collected from the Densu, Narkwa-Lagoon, and Whin estuaries. Mineral concentrations were analysed using an Atomic Absorption Spectrometer, with certified material (IAEA 461) as the reference standard. ANOVA was employed to compare the concentrations, and the Health Index (HI) and Cancer Index (CI) were assessed to evaluate potential health risks for women shellfishers consuming the oysters.

Results: Mean concentrations of dietary minerals (mg/kg wet weight) varied significantly across the Densu, Narkwa-Lagoon, and Whin estuarine sites: Selenium (4.6, 5.9, 5.7; p=0.014), Manganese (9.8, 7.0, 4.7, p<0.001), Copper (10.4, 7.7, 7.4; p<0.001), Iron (126, 147, 103; p<0.001), Zinc (64, 118, 66; p<0.001), Magnesium (1321, 1116, 374; p<0.001), and Calcium (3811, 840, 3445; p<0.001). Heavy metals also varied across sites: Arsenic (0.043, 0.189, 0.079; p<0.001), Mercury (0.027, 0.065, 0.022; p<0.001), Cadmium (0.023, 0.065, 0.025; p<0.001), and Lead (0.021, 0.058, 0.016; p=0.002). The Hazard Index (HI) for these heavy metals ranged from

0.0004 to 1.81 (mean: 0.071), and the Cancer Index (CI) ranged from 1.3 x 10^{-6} to 5.8 x 10^{-4} (mean: 7.0 x 10^{-5}) for inorganic arsenic, cadmium, and lead in oysters.

Conclusion: Oysters from these estuarine sites are rich in dietary minerals like iron and zinc, but heavy metals pose risks. Reducing estuarine pollution is crucial to ensure safe, nutrient-rich oysters for consumers.

Keywords: mangrove oysters, dietary mineral concentration, shellfish, women, and heavy metals.

8.1 Background

Micronutrient deficiencies, particularly of iron and zinc, are widespread and pose significant public health challenges globally. Key contributors to these deficiencies include inadequate dietary intake (Ayensu et al., 2020; Codjoe et al., 2016) and an increased risk of infectious diseases (Gopalakrishnan et al., 2018; Shaw & Friedman, 2011). While micronutrient supplementation has routinely been employed to address these deficiencies, concerns about potential health risks associated with its use have emerged (FAO & WHO, 2018). Consequently, it is crucial to identify sustainable, safe, and nutritious solutions within food systems that align with existing dietary habits to effectively combat micronutrient deficiencies. Oysters emerge as an exceptional source of vitamins and minerals (USDA, 2020a) that could contribute to the overall well-being and reproductive health of women in coastal communities. Oysters play a vital role in ensuring food security for women shellfishers (Osei et al., 2021b), who rely on oysters for sustenance and income. In some instances, they are a primary source of dietary protein for their households (Chakraborty et al., 2016; Osei et al., 2020; Willer & Aldridge, 2019, 2020). Beyond their high protein content, oysters are rich in essential minerals, providing between 44% and over 100% of the recommended dietary allowance (RDA) for iron and zinc per 100 grams for women of

reproductive age (Asha et al., 2014; NIH, 2022a; SAGB, 2010). Additionally, oysters are valuable sources of selenium, manganese, and copper, which are crucial for well-being (Asha et al., 2014; Yoda et al., 2021). Thus, oysters can significantly alleviate micronutrient deficiencies, particularly those resulting from inadequate dietary intake among women of reproductive age. This is especially relevant in Ghana, where progress in addressing such deficiencies has been stagnant for the past three decades (Ecker & Asselt, 2017; GMS, 2017). In Ghana and other coastal African countries, approximately 55,000 individuals, primarily women, engage in estuarine and mangrove ecosystem-based shellfishery activities. The annual shellfish harvest in these regions exceeds 300,000 metric tons, valued at approximately USD 336 million (Chuku et al., 2022). However, data on mineral concentrations in oysters come from studies conducted outside Africa, particularly in the USA and China, which may not directly apply to West Africa due to differences in geographical locations, oyster species, and maturity levels (Greenfield & Southgate, 2003; Woke et al., 2016). The limited studies on oysters in Africa often involved small sample sizes (Abreu et al., 2020; Abu & Eli, 2018; Ampofo-Yeboah, 2014; Bodin et al., 2013), failing to account for the significant variability in micronutrient content found in biological samples (Greenfield & Southgate, 2003). Oysters, being filter feeders (Zhu et al., 2020), can accumulate high levels of heavy metals from their surrounding environment, posing significant health risks to humans (Erdem, 2015; Nour, 2020b). Oysters produced on the Ghana coast are feared to be contaminated due to improper waste disposal, the use of agricultural chemicals, and artisanal mining within the areas. These activities not only contribute to heavy metal contamination but also threaten the mangroves that support oyster production (Chuku et al., 2020; Osei et al., 2021b). While oysters have the potential to enhance the mineral intake of women shellfishers, they could also become sources of heavy metal contamination, leading to adverse health effects, including developmental,

neurological, immune, and systemic toxicity (Yousaf et al., 2016), and increasing the risk of cancer among consumers (Lin et al., 2013). Environmental conditions in Ghana, including pollution levels and types of contaminants, may differ significantly from those in other regions where data on oysters are available. Therefore, local assessments are essential to understand these unique risks and accurately evaluate safety measures to safeguard public health. The study sought to compare mineral concentrations in oysters across three selected estuarine sites in Ghana and to assess whether the levels of heavy metals present pose significant public health concerns.

8.2 Methods and Materials

8.2.1 Sampling and metal determination

In June and July 2021, mangrove oyster (*Crassostrea Tulipa*) specimens were collected from three selected estuarine sites in Ghana: Densu (5° 30' 55" N, 0° 18' 40" W), Whin (4° 52' 50" N, 1° 46' 46" W), and Narkwa Lagoon (5° 12' 26" N, 0° 55' 06" W), located in the Greater Accra, Western, and Central Regions, respectively. These sites were chosen due to the active involvement of women in shellfish harvesting, their reliance on mangrove ecosystems for sustenance, the health of the local fishing industry, and the level of mangrove degradation as identified by Chuku et al. (2020). To ensure reliable data, a large sample size was employed, addressing the natural variability in size, maturity, weight, and mineral content of wild, uncultivated oysters, as recommended by the FAO (Greenfield & Southgate, 2003). The sample size was calculated based on mean ± SD values for zinc (158 ± 61 mg/100g) and iron (40 ± 11 mg/100g) from Abreu et al. (2020), with a t-value at $\alpha = 0.05$ (2.262) and a 5% margin of error. This resulted in an estimated sample size of 305 oysters per site, providing sufficient statistical power for the analysis of all the minerals.

$$\text{Sample size} \geq (t_{\alpha\, n-1})^2\, SD^2 / (\text{accuracy} \times \text{mean})^2 \ldots\ldots\ldots\ldots\ldots \textit{Equation 1}$$

Sample sizes were allocated proportionally to the number of harvesting sites within each estuary. A local guide randomly collected the designated number of oysters from a 20 m² quadrat at each harvesting site (Baggett, 2014). Sampling was conducted between 6:00 am and 10:00 am, aligning with the traditional practices of local women shellfishers. Post-harvest, oysters were shucked using knives, and the tissues were carefully cleaned with a soft brush, weighed, and sealed in air-tight dispensing envelopes. These envelopes were then placed in ice-conditioned containers for preservation during transport to the laboratory. Samples were stored at –86 °C until analysis. For mineral analysis, the entire oyster tissues were digested in 10 mL of nitric acid (HNO_3) and 5 mL of sulfuric acid (H_2SO_4). The mixtures were heated at 95 °C for 1–3 hours until the substrates darkened in colour. After cooling to room temperature, 2 mL of 30% hydrogen peroxide (H_2O_2) was added as an oxidizing agent, and the solutions were reheated for 20 minutes until they became colourless. The digested samples were then diluted to 100 mL with distilled water in volumetric flasks and stored in clean containers for mineral content measurement. Mineral concentrations were determined using an Atomic Absorption Spectrometer (AAS; PinAAcle 900T, PerkinElmer, Kentucky, USA). Elements including Ca, Mg, Na, K, Fe, Cu, Ni, Zn, Co, Mn, Pb, Cr, and Cd were quantified using flame atomic absorption spectrometry (FAAS) with air–acetylene gas as the fuel source (Agemian et al., 1980; Edgell, 1989). Arsenic (As) and mercury (Hg) concentrations were measured using hydride generation and cold vapor techniques, respectively, with argon gas as the carrier. For phosphorus (P) determination, 2–3 drops of a mixture containing p-nitrophenol and ammonium hydroxide (NH_4OH), 5 mL of ascorbic acid [containing ammonium molybdate ($(NH_4)_6Mo_7O_{24}$) and sulfuric acid (H_2SO_4)], and reagent A [potassium antimonyl tartrate, $K_2Sb_2(C_4H_2O_6)_2$] were added to 1 mL aliquots of each sample in separate 50 mL volumetric flasks.

The solutions were diluted to 50 mL with distilled water and allowed to react for 30 minutes to develop colour (Cho & Nielsen, 2017; Nielsen, 2017). Total phosphorus was then measured using a Spectroquant Pharo 300 UV–visible spectrophotometer.

8.2.2 Quality control

All reagents used were of analytical grade. Prior to analysis, all plastic and glassware were soaked in a 10% nitric acid (HNO_3) solution for 24 hours to eliminate potential contaminants. They were then thoroughly rinsed with distilled water and dried overnight in an oven. Blank analyses were performed concurrently during the digestion process to monitor for any contamination. Each sample was analysed in triplicate, with quality control checks conducted every 20 samples. Two standards were assessed to detect any interference or cross-contamination. The observed percentage recovery of the analysed metals ranged from 92.6% to 101.7%, as shown in the Supplementary Sheet 4. To ensure quality control, certified reference material IAEA 461, derived from marine biota (clam *Gafrarium tumidum*), was included in each batch of sample digestion and analysed according to the established protocol.

8.2.3 Data analysis

Data analysis was conducted using R software version 4.3.1. The normality of mineral concentration data was assessed using quantile–quantile (Q–Q) plots and confirmed with the Shapiro–Wilk test; p-values exceeded 0.05 for 15 out of the 17 minerals analyzed, indicating normal distribution. Mineral concentrations were reported as means ± standard deviations (SD) and compared across estuarine sites using analysis of variance (ANOVA). Additionally, the study reported the proportions of oysters with heavy metal concentrations exceeding the European Union

(EU) regulatory maximum limits for molluscs: lead (Pb) at 1.5 mg/kg, mercury (Hg) at 0.5 mg/kg, cadmium (Cd) at 1.0 mg/kg, and arsenic (As) at 0.09 mg/kg wet weight (EFSA, 2006). To assess the potential public health risks associated with oyster consumption among women shellfishers, the estimated daily intake (EDI) of heavy metals was calculated. This calculation involved multiplying the concentration of heavy metals (C, in mg/kg wet weight) by the average rate of oyster consumption (AC, in g/day) and then dividing by the average body weight (Bwt) of the women shellfishers, which was estimated to be 63.5 kg in the present study. The formula used is as follows:

$$EDI = \frac{(C \times AC)}{(Bwt)} \quad \text{..... } \textit{Equation 2}$$

This method follows the approach described by Yi et al. (2017) and Zhong et al. (2018). The calculated EDIs for each heavy metal were then compared to the tolerable daily intake levels established by the European Food Safety Authority (EFSA, 2009a, 2010, 2015) to evaluate heavy metal intakes among women shellfishers. Additionally, the non-carcinogenic adverse effects associated with oyster consumption from the three estuaries were assessed using the Target Hazard Quotient (THQ) in equation 3. Where, 10^{-3} is the unit conversion factor. The DE, LEG, DIR, C, RfDo, and ATn respectively represent the number of days participants were exposed to contaminants in a year (365 days/year), the average life expectancy of Ghanaian women [65 years] (KNOEMA, 2020), the daily ingestion rate of the oysters (g/day), the concentrations of heavy metals in the oyster samples – the study estimated the average percent inorganic As (i-As) in the oyster samples using 30% of the total As in a worst-case scenario (Lorenzana et al., 2009), the oral reference doses (As: 0.0003 mg/kg/day, Hg: 0.0001 mg/kg/day, Cd: 0.001 mg/kg/day, and Pb: 0.0035 mg/kg/day) (Holloman & Newman, 2012; USEPA, 2018), and the average lifetime exposure (365 days/year x 65 years) participants are most likely to experience non-carcinogenic

effects or otherwise. The THQ measures the ratio of the estimated daily intake (EDI) of contaminants to their oral reference doses (RfD) (Equation 3) (Yi et al., 2017; Zhong et al., 2018). A unit conversion factor of 10^{-3} was applied. The exposure frequency (EF) was set at 365 days per year, representing daily consumption, and the exposure duration (ED) corresponded to the average life expectancy of Ghanaian women, 65 years (knoema, 2020). The daily ingestion rate (DIR) of oysters measured in the current study was 46.33 g/day. The contaminant concentration (C) represented the levels of heavy metals in the oyster samples, with arsenic toxicity limited to inorganic arsenic, estimated at 30% of total arsenic in a worst-case scenario (Lorenzana et al., 2009). The oral reference doses were RfD_{As}: 0.0003 mg/kg/day, RfD_{Hg}: 0.0001 mg/kg/day, RfD_{Cd} : 0.001 mg/kg/day, and RfD_{Pb}: 0.0035 mg/kg/day (Holloman & Newman, 2012; USEPA, 2018). The average body weight (BW) of the women shellfishers was 63.5 kg. The averaging time for non-carcinogens (ATn was calculated as EF × ED (365 days/year × 65 years). THQ values were categorized based on risk levels: ≤ 1 (no significant risk), 1–9.9 (low risk), 10–19.9 (moderate risk), 20–99.9 (high risk), and ≥ 100 (serious risk) of mineral contamination from oyster consumption (Wang et al., 2018; Zhong et al., 2018). The total non-carcinogenic health effect (Hazard Index-HI) was then estimated by summing the THQ of all heavy metal consumed. Wang et al. (2018) found that humans are often expose and suffer from combined effects of the heavy metals due to nutrient-nutrient interactions in the body. As such, HI greater than 1, also indicated the possibility of adverse effects associated with the consumption of the oysters. The severity of the risk of adverse effects increases with increasing values of the HI (Wang et al., 2018; Yi et al., 2017).

$$THQ = \frac{(DE \times LEG \times DIR \times C)}{(RfDo \times Bwt \times ATn)} \times 10^{-3} \quad \text{..... } \textit{Equation 3}$$

To evaluate the carcinogenic risks associated with oyster consumption among women shellfishers, the Target Cancer Risk (TCR) was calculated using Equation 4. This assessment involved applying oral slope factors for heavy metals, arsenic (As): 1.5 $(mg/kg/day)^{-1}$, cadmium (Cd): 6.1 $(mg/kg/day)^{-1}$, and lead (Pb): 8.5 $(mg/kg/day)^{-1}$, as reported by Antoine et al. (2017) and Mohammadi et al. (2019), along with the estimated daily doses of these carcinogens. The TCR values obtained for each heavy metal at each estuarine site were compared to the U.S. Environmental Protection Agency's (USEPA) acceptable cancer risk range of 1×10^{-6} to 1×10^{-4}, corresponding to a risk of 1 in 1,000,000 to 1 in 10,000 individuals (Gbogbo et al., 2018). TCR values were categorized as follows: $\leq 1 \times 10^{-6}$ (low risk), 1×10^{-6} to 1×10^{-4} (moderate risk), 1×10^{-4} to 1×10^{-1} (high risk), and $\geq 1 \times 10^{-1}$ (very high risk) (Aguilar et al., 2021). Similarly, due to the cumulative chemical and biological effects of heavy metals, Cancer Index (CI) used in this study is defined as the sum TCR of Arsenic, lead, and cadmium. The estimation of these risks are based on the assumptions that the processing and the amount of the minerals in the oyster ingested are the same as the amount absorbed (Yi et al., 2017).

$$TCR = \frac{(DE \times LEG \times DIR \times C \times CSF)}{(Bwt \times ATn)} \times 10^{-3} \quad \ldots\ldots\ldots\ldots \textit{Equation 4}$$

Physiological selenium (Se) interacts with nutrients to counteract the toxicity of heavy metals such as Cd, As, and Pb (Gbogbo et al., 2018; Zwolak, 2020). Adequate levels of physiological Se have the potential to suppress the undesirable chemical or biological activities of these heavy metals. This suppression is determined by the relative amount of available physiological Se in relation to the sum of the heavy metal and Se concentrations, as described by Equation 5. In this equation, HBV-Se represents the health benefit value of Se, and HM denotes the concentration of the specific heavy metal in the oyster samples. A positive or negative HBV indicates whether the presence of the heavy metal enhances or diminishes the Se status, with the magnitude of the value

accurately reflecting the surplus or deficiency of Se resulting from oyster consumption (Ralston et al., 2016).

$$HBV\text{-}_{Se} = (Se - HM)/Se \times (Se + HM) \quad \text{..... } \textit{Equation 5}$$

8.3 Results

8.3.1 Macromineral concentrations in oysters

Table 7.1 presents the mean concentrations of macrominerals (mg/kg wet weight) detected in oysters from the three estuarine sites, listed in descending order of abundance: sodium (Na) at 6,924 ± 4,822, potassium (K) at 4,282 ± 4,567, phosphorus (P) at 3,470 ± 5,416, calcium (Ca) at 2,698 ± 3,216, and magnesium (Mg) at 937 ± 559. These results indicate that macromineral concentrations in oysters vary significantly among different estuarine sites ($p < 0.001$). Specifically, the Na concentration in oysters from the Narkwa estuary was significantly higher than in those from the Densu and Whin estuaries (9,689 ± 2,990 mg/kg vs. 8,051 ± 5,315 mg/kg and 3,031 ± 2,929 mg/kg, respectively; $p < 0.001$). Similarly, the P concentration in oysters from Narkwa (5,016 ± 8,367 mg/kg) was significantly higher than in oysters from Whin (2,513 ± 3,101 mg/kg) and Densu (2,882 ± 2,219 mg/kg) estuaries ($p < 0.001$). In contrast, the concentrations of K, Ca, and Mg were significantly higher in oysters from the Densu estuary compared to those from Narkwa and Whin. The K concentration was highest in Densu oysters (8,314 ± 5,620 mg/kg), followed by those from Narkwa (3,090 ± 2,181 mg/kg) and Whin (1,443 ± 755 mg/kg) ($p < 0.001$). Similarly, Ca concentrations were higher in Densu oysters (3,811 ± 2,878 mg/kg) compared to Narkwa (840 ± 940 mg/kg) and Whin (3,445 ± 4,081 mg/kg), with the Whin estuary showing a wide variation ($p < 0.001$). For Mg, Densu oysters had significantly higher levels (1,321 ± 453 mg/kg) than those from Narkwa (1,116 ± 409 mg/kg) and Whin (374 ± 264 mg/kg) ($p < 0.001$).

Table 7.1: Comparable mean macromineral concentrations of oysters from the three estuarine sites.

Estuary/Mineral	Weight	Concentrations, mg/kg wet weight				
		Na	K	P	Ca	Mg
Densu (n = 305)	2.89 ± 1.45[b]	8051 ± 5315[b]	8314 ± 5620[a]	2882 ± 2219[b]	3811 ± 2878[a]	1321 ± 453[a]
Narkwa (n = 305)	1.70 ± 1.86[c]	9689 ± 2990[a]	3090 ± 2181[b]	5016 ± 8367[a]	840 ± 940[b]	1116 ± 409[b]
Whin (n = 305)	3.35 ± 1.87[a]	3031 ± 2929[c]	1443 ± 755[c]	2513 ± 3101[b]	3445 ± 4081[a]	374 ± 264[c]
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
All sites (n = 915)	2.65 ±1.87	6924 ± 4822	4282 ± 4567	3470 ± 5416	2698 ± 3216	937 ± 559

[1]Values in a column with a differing letter statistically differ from each other at $\alpha < 0.05$ by ANOVA and Tukey HSD tests for means.

8.3.2 Trace mineral concentrations in oysters

Trace mineral concentrations (mg/kg wet weight) in the oyster samples, listed in descending order, were as follows: iron (Fe) at 125.5 ± 110.6, zinc (Zn) at 82.4 ± 71.1, cobalt (Co) at 27.3 ± 26.8, chromium (Cr) at 22.1 ± 30.0, nickel (Ni) at 22.0 ± 23.6, copper (Cu) at 8.5 ± 5.7, manganese (Mn) at 7.2 ± 8.5, and selenium (Se) at 5.4 ± 6.0 (Table 2). Six of these trace elements: Fe, Zn, Co, Cr, Ni, and Se, were significantly higher in oysters from the Narkwa estuary compared to those from the Densu and Whin estuaries ($p < 0.001$). For example, Fe concentrations were markedly higher in Narkwa oysters (147 ± 142 mg/kg) than in those from Densu (126.1 ± 9 mg/kg) and Whin (103 ± 87 mg/kg). Similarly, Zn levels were elevated in Narkwa oysters (118 ± 79 mg/kg) compared to Whin (65.5 ± 62.1 mg/kg) and Densu (64.0 ± 56.3 mg/kg). Conversely, Cu and Mn concentrations were highest in oysters from the Densu estuary (10.4 ± 6.6 mg/kg and 9.76 ± 8.67 mg/kg, respectively), followed by those from Narkwa (Cu: 7.74 ± 2.83 mg/kg; Mn: 7.02 ± 9.79 mg/kg) and Whin (Cu: 7.39 ± 6.41 mg/kg; Mn: 4.66 ± 5.84 mg/kg), with significant differences across sites ($p < 0.001$) (Table 7.2).

Table 7.2: Comparable mean concentrations of trace minerals of oysters from the three estuarine sites in Ghana.

Estuary/Mineral	Concentration, mg/kg wet weight							
	Fe	Zn	Co	Cr	Ni	Cu	Mn	Se
Densu (n = 305)	126.1 ± 9[b]	64.0 ± 56.3[b]	20.4 ± 15.4[b]	14.1 ± 22.3[b]	17.0 ± 17.2[b]	10.4 ± 6.6[a]	9.8 ± 8.7[a]	4.6 ± 3.6[b]
Narkwa (n = 305)	147.1 ± 141.9[a]	117.8 ± 79.1[a]	30.5 ± 30.8[a]	27.9 ± 38.2[a]	33.5 ± 30.2[a]	7.7 ± 2.8[b]	7.0 ± 9.8[b]	5.9 ± 7.4[a]
Whin (n = 305)	103.4 ± 87.3[c]	65.5 ± 62.1[b]	31.0 ± 29.9[a]	24.5 ± 24.3[a]	15.6 ± 16.3[b]	7.4 ± 6.4[b]	4.7 ± 5.8[c]	5.7 ± 6.2[a]
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.014
All sites (n = 915)	125.5 ± 110.6	82.4 ± 71.1	27.3 ± 26.8	22.1 ± 30.0	22.0 ± 23.6	8.5 ± 5.7	7.2 ± 8.5	5.4 ± 6.0

[1]Values in a column with a differing letter statistically differ from each other at $\alpha < 0.05$ by ANOVA and Tukey HSD tests for means

8.3.3 Heavy metals contaminations in oysters

Table 7.3 presents the mean concentrations of heavy metals: arsenic (As), mercury (Hg), cadmium (Cd), and lead (Pb) in oysters from the three estuarine sites. The overall mean concentrations (mg/kg wet weight) were 0.102 ± 0.132 for As, 0.038 ± 0.083 for Hg, 0.037 ± 0.039 for Cd, and 0.032 ± 0.037 for Pb. Oysters from the Narkwa estuary exhibited significantly higher levels of these heavy metals compared to those from the Densu and Whin estuaries. Specifically, the mean As concentration in Narkwa oysters was significantly elevated (0.102 mg/kg) compared to Densu and Whin oysters, with values ranging from 0.043 to 0.079 mg/kg ($p < 0.001$). The Hg concentration in Narkwa oysters was approximately twice that of oysters from Whin and Densu (0.065 ± 0.132 mg/kg vs. 0.027 ± 0.038 mg/kg and 0.022 ± 0.025 mg/kg, respectively; $p < 0.001$). Cd concentrations across all samples ranged from 0.023 to 0.065 mg/kg, averaging 0.037 mg/kg, with Narkwa oysters showing higher levels. Pb concentrations were also significantly higher in Narkwa oysters (0.058 ± 0.046 mg/kg) compared to those from Densu (0.016 ± 0.021 mg/kg) and Whin (0.021 ± 0.021 mg/kg) estuaries ($p = 0.002$).

Table 7.3: Comparable mean concentrations of heavy metals in oysters from the three estuarine sites

Estuary/Mineral	Concentration, mg/kg wet weight			
	As	Hg	Cd	Pb
Densu (n = 305)	0.043 ± 0.032[c]	0.027 ± 0.038[b]	0.023 ± 0.017[b]	0.021 ± 0.021[b]
Narkwa (n = 305)	0.189 ± 0.167 (280)[a,†]	0.065 ± 0.132[a]	0.065 ± 0.051[a]	0.058 ± 0.046[a]
Whin (n = 305)	0.079 ± 0.116[b]	0.022 ± 0.025[b]	0.025 ± 0.026[b]	0.016 ± 0.021[b]
P-value	<0.001	<0.001	<0.001	0.002
All sites (n = 915)	0.102 ± 0.132 (890)[†]	0.038 ± 0.083	0.037 ± 0.039	0.032 ± 0.037
EU Regulatory Limits	0.09	0.5	1.0	1.5

[1]Values in a column with a differing letter statistically differ from each other at $\alpha < 0.05$ by ANOVA and Tukey HSD tests for means . [†] Indicates lower sample size than the previously estimated figure. The maximum regulatory levels set by the EU (EFSA, 2006) were comparable standards.

8.3.4 Estimated Daily Intake

Table 7.4 summarises the Estimated Daily Intake (EDI) of heavy metals derived from oyster consumption across the various estuarine sites. The highest percentage of heavy metals exceeding the Maximum Allowable Limit (MAL) was observed for inorganic arsenic (As), accounting for 7.1% of the overall samples. The mean EDI for inorganic As was calculated to be 4.1 x 10^{-6} µg/kg/d, with a range from 0 to 4.9 x 10^{-5} µg/kg/d. The mean EDI for inorganic As was 4.1×10^{-6} µg/kg/day, ranging from 0 to 4.9×10^{-5} µg/kg/day, which is significantly below the Joint FAO/WHO Expert Committee on Food Additives (JECFA) recommendation of 2.1 µg/kg/day. Cadmium (Cd) and lead (Pb) concentrations were below the MAL in all samples. The mean EDI for Cd was 5.0×10^{-6} µg/kg/day (range: 4.0×10^{-7} to 4.5×10^{-5} µg/kg/day), and for Pb, it was 4.3×10^{-6} µg/kg/day (range: 8.2×10^{-8} to 3.7×10^{-5} µg/kg/day). Mercury (Hg) exceeded the MAL in only 0.7% of samples, with a mean EDI of 5.2×10^{-6} µg/kg/day (range: 2.0×10^{-7} to 1.8×10^{-4} µg/kg/day). Across individual estuarine sites, the EDI for inorganic As ranged from 1.8×10^{-6} µg/kg/day in the Densu Estuary to 7.6×10^{-6} µg/kg/day in the Narkwa Estuary. Cadmium and Pb intakes were consistently low across all sites, with Cd EDI ranging from 3.0×10^{-6} µg/kg/day (Densu) to 8.7×10^{-6} µg/kg/day (Narkwa). Mercury intake varied, with the highest EDI observed in Narkwa (8.7×10^{-6} µg/kg/day), indicating elevated Hg exposure compared to other estuaries. Overall, the EDIs for all heavy metals among women shellfishers were substantially below the recommended tolerable daily intake levels established by the EU.

8.3.5 Non-carcinogenic adverse health risk

The Target Hazard Quotient (THQ) assesses the potential for non-carcinogenic adverse health effects from metal exposure (Table 7.4). Using an average body weight of 63.5 kg and a daily

oyster consumption rate of 8.55 g/person/day (based on two non-consecutive 24-hour dietary recalls), we calculated the THQs for heavy metals. The mean THQ for inorganic arsenic across all estuarine sites was 1.4×10^{-2}, ranging from 0 to 0.16. Cadmium and lead exhibited low THQ values of 5.0×10^{-3} (range: 3.6×10^{-4} to 4.5×10^{-5}) and 1.2×10^{-3} (range: 2.4×10^{-5} to 1.1×10^{-2}), respectively. Mercury showed a higher THQ of 0.052 (range: 1.7×10^{-3} to 1.75), but still within acceptable limits, indicating minimal risk for non-carcinogenic health effects. The Hazard Index (HI), representing the cumulative non-carcinogenic risk from all metals, remained below 1 in all cases, indicating no significant health risk. Inorganic arsenic contributed the most to the HI, with a mean of 0.071 (range: 4.4×10^{-3} to 1.81). The Densu Estuary exhibited the highest HI for inorganic arsenic at 0.046 (range: 5.6×10^{-3} to 0.81), while the Narkwa Estuary showed the highest cumulative HI at 0.121 (range: 1.1×10^{-2} to 1.81), primarily due to elevated levels of arsenic and mercury.

8.3.6 Carcinogenic health risk

The carcinogenic health risks from oyster consumption were assessed using the Target Cancer Risk (TCR) and Cancer Index (CI) (Table 7.4). For inorganic arsenic, the mean TCR across all estuarine sites was 6.1×10^{-6}, ranging from 0 to 7.3×10^{-5}, indicating an extremely low cancer risk. Cadmium and lead had minimal impacts on cancer risk, with TCRs of 3.0×10^{-5} (range: 2.0×10^{-6} to 2.7×10^{-4}) for cadmium and 3.6×10^{-5} (range: 7.0×10^{-7} to 3.2×10^{-4}) for lead. The CI for these heavy metals remained low across all sites, averaging 7.0×10^{-5}. Specifically, the Densu Estuary exhibited a CI of 4.5×10^{-5} (range: 5.3×10^{-6} to 2.5×10^{-4}), while the Narkwa Estuary showed the highest CI at 1.2×10^{-4} (range: 1.6×10^{-6} to 5.8×10^{-4}), both falling within the low cancer risk category.

Table 7.4: Estimated daily intake, carcinogenic and non-carcinogenic health effects from heavy metal concentrations in oyster samples.

Site	% of oysters with HM concentration Above MAL	Mean EDI (Lower, Upper limit) ug/kg/d	JECFA (EFSA) EDI ug/kg/d	Mean THQ (Lower, Upper limit)	Mean HI (Lower, Upper limit)	Mean TCR (Lower, Upper limit)	Mean CI (Lower, Upper limit)	HBV-$_{Se}$
All Estuarine sites								
i-Arsenic	7.1	4.1×10^{-6} ($0, 4.9 \times 10^{-5}$)	2.1 (0.04 - 1.14)	1.4×10^{-2} (0, 0.16)		6.1×10^{-6} ($0, 7.3 \times 10^{-5}$)		
Cadmium	0	5.0×10^{-6} (4.0×10^{-7}, 4.5×10^{-5})	0.83 (0.36)	5.0×10^{-3} (3.6×10^{-4}, 4.5×10^{-5})	0.071 (4.4×10^{-3}, 1.81)	3.0×10^{-5} (2.0×10^{-6}, 2.7×10^{-4})	7.0×10^{-5} (1.3×10^{-6}, 5.8×10^{-4})	5.377 (0.052, 94.443)
Lead	0	4.3 x 10-6 (8.2×10^{-8}, 3.7×10^{-5})	3.57 (0.07)	1.2×10^{-3} (2.4×10^{-5}, 1.1×10^{-2})		3.6×10^{-5} (7.0×10^{-7}, 3.2×10^{-4})		
Mercury	0.7	5.2×10^{-6} (2.0×10^{-7}, 1.8×10^{-4})	0.57 (0.19)	0.052 (1.7×10^{-3}, 1.75)				
Whin Estuary								
i-Arsenic	3.9	3.2×10^{-6} ($0, 4.9 \times 10^{-5}$)	2.1 (0.04 - 1.14)	0.01 (9.5×10^{-5}, 0.16)		4.8×10^{-6} ($0, 7.3 \times 10^{-5}$)		
Cadmium	0	3.4×10^{-6} (4.0×10^{-7}, 2.8×10^{-5})	0.83 (0.36)	3.4×10^{-3} (3.6×10^{-4}, 2.8×10^{-2})	0.044 (4.4×10^{-3}, 0.26)	2.1×10^{-5} (2.0×10^{-6}, 1.7×10^{-4})	4.2×10^{-5} (5.8×10^{-6}, 3.7×10^{-4})	5.710 (0.052, 78.000)
Lead	0	2.1×10^{-6} (8.2×10^{-8}, 2.1×10^{-5})	3.57 (0.07)	6.1×10^{-4} (2.4×10^{-5}, 6.1×10^{-3})		1.8×10^{-5} (7.0×10^{-7}, 1.8×10^{-4})		

Mercury	0	3.0×10^{-6} (2.0×10^{-7}, 2.6×10^{-5})	0.57 (0.19)	0.030 (0.017, 0.26)				
Densu Estuary								
i-Arsenic	0	1.8×10^{-6} (4.0×10^{-7}, 1.0×10^{-5})	2.1 (0.04 - 1.14)	5.8×10^{-3} (1.2×10^{-3}, 3.5×10^{-2})	0.046 (5.6×10^{-3}, 0.81)	2.6×10^{-6} (5.0×10^{-7}, 1.6×10^{-5})	4.5×10^{-5} (5.3×10^{-6}, 2.5×10^{-4})	4.568 (0.319, 19.822)
Cadmium	0	3.0×10^{-6} (6.0×10^{-7}, 2.0×10^{-5})	0.83 (0.36)	3.0×10^{-3} (6.3×10^{-4}, 2.0×10^{-2})		1.9×10^{-5} (4.0×10^{-6}, 1.2×10^{-4})		
Lead	0	2.8×10^{-6} (1.9×10^{-7}, 2.0×10^{-5})	3.57 (0.07)	8.1×10^{-4} (5.5×10^{-5}, 5.6×10^{-3})		2.4×10^{-5} (1.6×10^{-6}, 1.7×10^{-4})		
Mercury	0.3	3.7×10^{-6} (3.0×10^{-7}, 7.6×10^{-5})	0.57 (0.19)	0.037 (2.9 x 10-3, 0.76)				
Narkwa Estuary								
i-Arsenic	17.4	7.6×10^{-6} (0, 4.6×10^{-5})	2.1 (0.04 - 1.14)	2.5×10^{-2} (0, 0.15)	0.121 (1.1×10^{-2}, 1.81)	1.1×10^{-5} (0, 6.8×10^{-5})	1.2×10^{-4} (1.6×10^{-6}, 5.8×10^{-4})	5.855 (0.166, 94.443)
Cadmium	0	8.7×10^{-6} (4.0×10^{-7}, 4.5×10^{-5})	0.83 (0.36)	8.7×10^{-3} (3.6×10^{-4}, 4.5×10^{-2})		5.3×10^{-5} (2.0×10^{-6}, 2.7×10^{-4})		
Lead	0	7.8×10^{-6} (2.0×10^{-7}, 3.7×10^{-5})	3.57 (0.07)	2.2×10^{-3} (5.6×10^{-5}, 1.1×10^{-2})		6.6×10^{-5} (1.7×10^{-6}, 3.2×10^{-4})		
Mercury	1.6	8.7×10^{-6} (6.0×10^{-7}, 1.8×10^{-5})	0.57 (0.19)	0.087				

		[4])		(5.8 x 10-3, 1.75)				

[1]350 oyster species were sampled from Densu, Whin, and Narkwa estuarine sites, n = 305; Narkwa site, n = 305; Whin site, n = 305.

[2]EDI: Estimated Daily Intake of Metals was expressed as the ratio of the product of metal concentration, C, from oysters (mg/kg wet weight) and the average daily oyster consumption of women shellfishers, ADC (kg), to the average body weight (BW) of women shellfishers (kg) (Yi et al., 2017; Zhong et al., 2018).

[3]THQ, or Target Hazard Quotient, was expressed as the ratio of exposure (estimated daily intake, [EDI]) to the oral reference dose (RfD) (Wang et al., 2018; Zhong et al., 2018).

[4]HI, Hazard Index, is the sum of the THQ of all heavy metals (Joseph et al., 2021; Moslen & Miebaka, 2017), i.e., HI = THQiarsenic + THQcadmium + THQlead + THQmercury. HI > 1 indicates a potential health risk.

[5]Cancer Index (CI) is the sum of the target cancer risk (TCR) of Pb, Cd, and inorganic arsenic: TCRcadmium + TCRlead + TCRiarsenic. TCR or CI $\geq 10^{-1}$ indicates very high risk, 10^{-3} to 10^{-1} indicates high risk, 10^{-4} to 10^{-3} for moderate risk and $\leq 10^{-6}$ for low risk of cancer from oyster consumption.

[6]Health benefit values for physiological Se (HBV-se) were estimated following equation 5. The positive or negative HBV indicated that the presence of the heavy metal improves or lowers the status of Se, and the value's scale accurately depicts the Se surplus or shortage brought on by consuming the oysters (Ralston et al., 2016).

8.4 Discussion

8.4.1 Dietary minerals in oysters

This study compared the mineral concentrations of oysters from three estuarine sites in Ghana, demonstrating that oysters are a valuable source of essential dietary minerals, particularly. The large sample size and diverse site representation suggest the results accurately reflect oyster mineral content. The consumption of 100 grams of oysters could provide 69.7% (12.6 mg) of the recommended daily iron intake (18 mg) and 103% (8.2 mg) for zinc (8 mg) in women of reproductive age (WRA), making oysters an effective way to address micronutrient deficiencies, including iron-deficiency anaemia (Asare et al., 2019; Yi et al., 2017). This is consistent with previous studies that highlight the high mineral content of oysters, particularly iron, calcium, and zinc (Ampofo-Yeboah, 2014; Liu et al., 2021; USDA, 2020b; Yoda et al., 2021; Yuan et al., 2020). They can contribute to the micronutrient needs, providing 27% of calcium, 49.6% of phosphorus, 29.3% of magnesium, 69% of copper, and 38.9% of manganese requirements. Given that women tend to consume oysters more frequently than men (Asare et al., 2019), promoting their consumption may improve dietary intake and mitigate micronutrient deficiencies in coastal populations, particularly among women and children. The mineral content found in this study aligns with levels reported in other regions, such as Nigeria and Japan (Woke et al., 2016; Yoda et al., 2021), although some variability exists due to factors like species, geographic location, and environmental conditions (Greenfield & Southgate, 2003; Machovsky-Capuska et al., 2018; Woke et al., 2016). The dietary mineral concentrations in these mangrove oysters are comparable to those found in other oyster species such as *C. gigas, C. angulate*, and *C. sikamea* (Liu et al., 2021; Wright et al., 2018; Zhu et al., 2018a). Overall, oysters from these estuarine sites are a rich source

of dietary minerals, and their regular consumption could significantly enhance the nutritional and health status of WRA in coastal communities.

8.4.2 Heavy metals in oysters

The nutritional benefits of oysters may be compromised by the presence of heavy metals, a common issue in seafood, including oysters, across both developed and low-resource regions (Wang et al., 2018). Elevated heavy metal levels can pose health risks if they exceed regulatory thresholds (EFSA, 2009b). In this study, all heavy metal concentrations in oysters were below the European Commission's regulatory limits, except for arsenic (EFSA, 2010). The higher arsenic levels align with previous findings, as marine species often accumulate this metal due to their feeding habits in demersal environments, where sediments contain higher concentrations of arsenic (EFSA, 2009b; Gbogbo et al., 2018). Mercury was the second most prevalent heavy metal detected, with significant variation across estuarine sites. The contamination is likely linked to activities such as artisanal gold mining, improper waste disposal, and the use of agricultural chemicals near these estuarine locations (Asare et al., 2019; Han et al., 2020; Osei et al., 2021b). The Narkwa estuarine site, in particular, showed elevated heavy metal levels, which is unsurprising given that the Okye River, which feeds into this lagoon, passes through areas of intensive gold mining (FCWC, 2017; Marfo, 2014). Mercury contamination poses the greatest risk to female shellfishers, with estimated daily intake (EDI) values suggesting significant exposure (EDI = 2.8 $\times 10^{-2}$ µg/kg/day). However, the lead and cadmium levels observed in this study were lower than those reported in Nigeria, Tanzania, and Senegal (Bodin et al., 2013; Mtanga & Machiwa, 2007; Woke et al., 2016). Furthermore, all four heavy metals were detected at lower concentrations in these oysters compared to studies conducted in regions such as Korea, China, Brazil, and Malaysia

(Mok et al., 2015; Wang et al., 2018). Despite the presence of heavy metals, particularly mercury and arsenic, the concentrations remain below harmful thresholds, with the exception of arsenic, which warrants caution. The findings emphasize the importance of considering local environmental factors like mining and agriculture, which may contribute to contamination. Nevertheless, the nutritional advantages of oyster consumption, particularly in terms of essential minerals, continue to be significant for improving health and nutritional outcomes.

8.4.3 Health risk from oyster consumption

The study evaluated both non-carcinogenic and carcinogenic health risks associated with heavy metal exposure from oyster consumption among women shellfishers. The EDI values for iAs, Pb, Cd, and Hg were found to be below the EFSA thresholds. Although the THQ and HI values were generally below 1, indicating minimal risk, the maximum THQ for mercury and HI exceeded 1 in about 0.4% of samples. This suggests a potential, albeit low, risk for adverse health effects, but given the large sample size of 915 oysters, the proportion is considered negligible. Overall, the mean HI of 0.071 suggests no significant non-carcinogenic risk from heavy metal exposure for women shellfishers. This aligns with previous studies by Gong et al. (2020) and García-Rico and Tejeda-Valenzuela (2020), who similarly found no substantial non-carcinogenic health risks from oyster consumption, although the number of heavy metals considered varies between studies. Variations in the reported health risks from other studies (Han et al., 2020; Vieira et al., 2021; Wang et al., 2018) can be attributed to differences in the heavy metals analysed and the consumption rates of oysters among different populations. Studies like those by Wang et al. (2018) and Vieira et al. (2021), which assessed a larger number of heavy metals, showed higher HI values, reflecting greater potential risk. This indicates that the inclusion of additional

heavy metals in risk assessments can yield a more comprehensive evaluation of health hazards. It is important to note, however, that the presence of certain heavy metals such as Zn, Cr, Cu, Ni, and Mn, as reported in previous studies, does not necessarily pose a health risk unless their concentrations exceed established safety thresholds. In fact, these minerals play essential roles in women's reproductive health (Garner et al., 2021; Soetan et al., 2010) and contribute to various physiological functions (Shaffer & Thomas, 2023). Therefore, this study focused on heavy metals like As, Hg, Cd, and Pb, as these elements provide no known nutritional benefits and pose potential health risks even at low levels.

For carcinogenic risks, the study identified a low but acceptable risk related to iAs exposure from oyster consumption. This finding is consistent with Gong et al. (2020), who reported no significant cancer risk from arsenic in oysters in China. However, contrasting results have been noted in other regions, such as Japan and Brazil, where higher iAs levels in oysters and greater consumption rates contributed to a higher cancer risk (Han et al., 2020; Vieira et al., 2021). The variation in arsenic concentrations, which ranged from 10% inorganic in China to 90% in Japan, explains the differences in risk estimates. In this study, inorganic arsenic was estimated at 30%, a factor that likely contributed to the lower cancer risk. Cadmium and lead also posed moderate carcinogenic risks, consistent with findings by Gong et al. (2020) in China. This highlights the need to monitor permissible intake levels of these metals, especially among vulnerable groups like women. Environmental factors, such as artisanal mining and improper waste disposal in Ghana, likely contribute to the presence of these metals in estuarine environments (Ackah, 2017; World Bank Group, 2020). Interestingly, Se found in oysters may help mitigate heavy metal toxicity by forming inert complexes with metals like mercury and arsenic, reducing their harmful effects. For example, Se forms mercury selenide (HgSe), a highly insoluble and stable compound

that sequesters mercury in tissues, thereby preventing it from interfering with cellular function (Ralston et al., 2016; Zwolak, 2020). Similarly, Se has been shown to interact with arsenic to form selenium-arsenic complexes, such as glutathione–Se–As conjugates, which are more readily excreted by the body and reduce the bioavailability and genotoxicity of arsenic (Zwolak, 2020). Selenium's role in supporting antioxidant enzymes and aiding arsenic methylation further reduces the risk of metal-induced carcinogenicity. However, despite this potential protective mechanism, addressing the sources of heavy metal contamination in Ghana's estuarine environments remains a critical priority. This is essential before promoting oysters as a sustainable solution for addressing micronutrient deficiencies among women in coastal communities (GBN, 2021; Solidaridad, 2021). Nevertheless, there exists a compelling opportunity to extend the promotion of oyster consumption beyond estuarine communities to the national level, particularly considering the oyster's nutritional value and its significance in women's livelihoods. When the appropriate food safety measures are put in place, oysters can be positioned as a strategic nutrient-dense food to combat iron and zinc deficiencies across Ghana. Scaling up access and awareness through urban markets and national nutrition education campaigns would not only support broader dietary improvement but also stimulate economic opportunities for women shellfishers by expanding demand beyond local settings. This dual benefit underscores the necessity to integrate oyster promotion into national food and nutrition security strategies, albeit only in conjunction with rigorous monitoring of environmental contamination.

8.5 Strength and limitations of the study

The study had several strengths. It provided a comprehensive analysis of the mineral content in oysters and estimated the potential health risks associated with their consumption. The large, diverse sample size of oysters from three estuarine sites allowed for accurate estimates of their nutritional composition, following FAO guidelines for biological samples. To the best of my knowledge, this is the first study in Ghana, and possibly Africa, to assess the potential health risks of oyster consumption among women shellfishers. This provides comprehensive data on oysters, which can be useful in public health education on the promotion of oyster consumption locally.

8.5 Conclusion

The findings reveal that oysters contain substantial amounts of dietary minerals, particularly iron, zinc, magnesium, potassium, and calcium. The mineral composition of the oysters varied significantly across estuarine sites. Most minerals were found to be higher in Narkwa estuary than those from Densu and Whin estuarine sites. Nonetheless, the heavy metal levels in the oysters posed a threat to the potential nutritional benefits of consuming them. As a result, it is imperative to address the sources of pollution in the estuarine sites to promote the production and consumption of wholesome oysters, particularly among women shellfishers and other consumers.

Authors contribution

Francis Z. Taabia: investigation, writing - original draft, visualization. **Agartha N. Ohemeng:** writing - review & editing, supervision. **Seth Adu-Afarwuah:** conceptualization, funding acquisition, writing - review & editing. **Brietta M. Oaks:** funding acquisition, writing - review & editing.

Declaration of Interest

The authors assert that they possess no disclosed financial interests or personal relationships that may have exerted any influence on the research conducted and reported in this article.

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PART FOUR: DISCUSSION AND CONCLUSION

CHAPTER 9: General Conclusions and Policy Implications

9.1 Summary of Discussion

Food insecurity and malnutrition, particularly micronutrient deficiencies in zinc, calcium, and iron, continue to present major public health challenges, especially for women of reproductive age. These nutrients play crucial roles in reproductive health, and their deficiencies can lead to serious health risks for both mothers and their unborn children (Ali et al., 2020; WHO, 2023b). Despite ongoing public health interventions, including iron-folic acid (IFA) supplementation, the prevalence of anaemia among women has remained largely unchanged over the past three decades (GDHS, 1993, 2024). The Food and Agricultural Organization has advocated for sustainable, locally based food systems to address these deficiencies (FAO, 2019; USDA, 2020a). Oysters, which are rich in essential micronutrients, have the potential to contribute significantly to the diets of women shellfishers in coastal communities, particularly in addressing zinc and iron deficiencies. They are also critical for household food security in coastal communities. However, there is limited research on the mineral content of oysters in Ghana. Oyster data from regions outside of Africa may not account for the unique environmental and biological conditions present in West Africa. Furthermore, the degradation of mangrove ecosystems due to artisanal mining and other human activities poses a risk to oyster yields and, consequently, to the food security, nutritional status, and the entire livelihoods of women shellfishers (Asare et al., 2019; Osei et al., 2021a). Therefore, this study assessed and compared the prevalence and determined the factors associated with food security and the nutritional status of women shellfishers, as well as to evaluate the micronutrient content and potential health risks associated with oyster consumption. Additionally, the study

examined the nutrient intakes of women shellfishers and determined the contribution of oyster consumption to their total iron and zinc intakes.

The findings revealed that almost all women shellfishers experienced household food insecurity. This result could confirm the earlier warning about food insecurity in coastal communities highlighted in the Comprehensive Food Security and Vulnerability Analysis (CFSVA, 2012). The finding aligns with reports of heightened food insecurity (50–100%) from previous research conducted in Ghana among both farming and coastal households (Antwi et al., 2022; Armah et al., 2019; Asuru, 2020; Lambon-Quayefio & Owoo, 2021). The high prevalence of food insecurity may be due to several factors, including the depletion of shellfish populations and the increasing number of women engaging in shellfish harvesting (Agbekpornu et al., 2021), which could have led to reduced oyster yields for household sustenance and income. Additionally, the study coincided with a period when Ghana was emerging from COVID-19 public safety restrictions and a closed fishing season. These factors may have exacerbated food insecurity by disrupting food supply chains and reducing household income (Éliás & Jámbor, 2021; Hamadani et al., 2020; Swinnen & McDermott, 2020). The findings underscore the importance of considering maternal factors such as household asset ownership and the location of estuarine sites when planning food security interventions for women in coastal areas. Therefore, initiatives like those by USAID and DOPA to scale up mangrove and estuarine ecosystem sustainability practices, ensuring stable oyster production, could prove beneficial. Furthermore, the Ministries of Fisheries and Gender and Social Welfare should implement gender-sensitive social protection measures for women during the closed season to mitigate its impact on food security.

The study found that one in five women shellfishers was anaemic, aligning with two national surveys (Christian et al., 2022; Wegmüller et al., 2020) but half the rate reported in the recent

Demographic and Health Survey (GDHS, 2024). This lower prevalence may be attributed to better access to quality protein, such as fish, a rich source of dietary iron (Wheal et al., 2016). Women in the Densu estuarine sites were twice as likely to be anaemic as those in Whin, potentially due to peri-urban hygiene and sanitation challenges (Aydamo et al., 2023) and poor housing conditions among migratory women, increasing parasitic infection risk and lowering haemoglobin levels (Agbekpornu et al., 2021). These findings highlight geographic disparities in anaemia prevalence in low- and middle-income countries (Armah-Ansah, 2023; Bhandari et al., 2016; Habyarimana et al., 2020; Shitu & Terefe, 2022; Wegmüller et al., 2020). Improved sanitation infrastructure, clean water supply, and targeted education on hygiene and parasitic infections are needed to mitigate these risks. Overweight and obesity were protective against anaemia, consistent with studies in Ghana and elsewhere (Armah-Ansah, 2023; Gautam et al., 2019; Merid et al., 2023; Petry et al., 2021; Woldu et al., 2020), but contradictory to findings linking obesity with elevated hepcidin levels and reduced iron absorption (Lefebvre et al., 2014; Vaquero et al., 2021). These discrepancies may stem from comorbidities, such as diabetes, which influence serum iron levels independently of nutritional status (Hilton et al., 2023; Shubham et al., 2020). While adequate haemoglobin levels can be achieved without obesity, nutritional programmes addressing obesity management may support higher iron levels and improve overall health outcomes for women of reproductive age.

Approximately one in two women shellfishers was overweight or obese, with a higher prevalence observed in the Densu site (58.3%) compared to the national average (50%) (GDHS, 2024). The high prevalence of overweight and obesity may likely be attributed to sedentary lifestyles leading to reduced energy expenditure and possibly poor dietary choices. Another potential explanation is the emerging sociocultural preference for higher body weight among

Ghanaian women (Appiah et al., 2016). The findings suggest that overweight and obesity are significant public health concerns, particularly among women above 45 years in these coastal communities. The influence of sociocultural norms on body weight warrants further investigation. Public health campaigns addressing these perceptions and promoting a healthy body image may be necessary. Such campaigns could involve collaboration with community leaders and influencers to encourage a cultural shift toward healthier lifestyles. Additionally, given that many affected women are of reproductive age, integrating obesity prevention and management into reproductive health services could provide a more comprehensive approach. Policies to promote physical activity are also essential, especially considering gender disparities in physical activity levels among Ghanaian adults (Agyemang et al., 2022; Mensah et al., 2022). Balis et al. (2019) highlight that older adults in Ghana are receptive to physical activity interventions but lack knowledge of activity guidelines and how to meet them. Community-based fitness programmes or incentives for active living, supervised by healthcare providers, could address these gaps (Balis et al., 2019). Initiatives should include the creation of safe, accessible spaces for exercise to promote physical activity and reduce obesity prevalence effectively.

The findings revealed that women shellfishers exhibited significantly lower daily calorie intakes, averaging 1,464.5 kcal. The inadequate energy intake could be due to the combined result of the high prevalence of food insecurity in the study area and the ongoing impact of the COVID-19 pandemic, along with its associated restrictions on both local and global food systems, which have contributed to an increase in food costs for low-income earners in urban centres such as the Densu site (Adusei, 2021). Moreover, over half of the women (53–99%) failed to meet the recommended intake levels for essential micronutrients such as zinc, iron, and calcium. The mean adequacy ratio for six critical micronutrients indicated that women shellfishers achieved only 62%

of the recommended dietary intake. These inadequacies align with findings reported in both developed and developing settings (Harika et al., 2017; Milman, 2019) and can be attributed to the high levels of food insecurity and poor dietary diversity observed in this population. Despite the high mineral content of oysters, the suboptimal consumption patterns noted among these women may have contributed to the observed nutrient inadequacies. The reduced calorie and micronutrient intakes could have serious nutritional implications for reproductive health. A decline in maternal nutrient intake may adversely affect mitochondrial function (Herring et al., 2018)and contribute to adverse pregnancy outcomes, including low birth weight, preterm delivery, and developmental challenges for their children. These dietary inadequacies may also predispose women to anaemia, fatigue, compromised immune function, and long-term physical health issues. Addressing these nutritional challenges is essential for improving the health and well-being of women shellfishers and their families. Although oysters contributed approximately 20% of the total iron intake among participants, this did not result in improved anaemia outcomes. This lack of impact may be attributed to the low iron adequacy ratio in their overall diets and the limited oyster consumption among the women.

This study provides valuable information on the mineral content of oysters consumed by women shellfishers in Ghana. A 100-gram serving of oysters was found to provide approximately 12.6 mg of iron and 8.2 mg of zinc on average, which could meet around 69.7% and 103% of the recommended daily allowance for these minerals, respectively. However, the low dietary intake of iron and zinc observed in this study, alongside the high prevalence of anaemia, can be attributed to several interrelated factors. Oyster consumption was low (average of 8.6 g/day) lower than reported levels in Asia but higher than in Western countries like the US and France (García-Rico & Tejeda-Valenzuela, 2020; Prod'homme, 2023), and only 12.5% of women reported consuming

oysters regularly. This is largely due to the widespread practice of selling oysters for income, as many shellfishers rely on oyster harvesting as a livelihood strategy rather than a food source (Hayford, 2021; Janha et al., 2017b). Consequently, despite the nutritional richness of oysters, women prioritise economic survival over dietary use. The study also revealing no significant non-carcinogenic risks but a low to moderate cancer risk from exposure to inorganic arsenic, cadmium, and lead. However, the high selenium content in oysters may mitigate these risks. These findings underscore the importance of regular monitoring for contaminants, particularly given the environmental challenges faced by estuarine ecosystems in Ghana. Protecting mangrove ecosystems is essential for maintaining sustainable oyster harvesting, and efforts to reduce pollution from artisanal mining should be prioritized to ensure the continued availability of this valuable food source.

9.2 Conclusion and Policy Implications

This study provides critical insights into the food security, nutritional status and health risks among women shellfishers in Ghana, emphasizing the dual burden of obesity and micronutrient inadequacies. The findings highlight the need for integrated public health interventions that focus on both managing obesity and improving nutrient intake. There is also a pressing need for regular monitoring of oyster contamination and efforts to protect the mangrove ecosystems that support the livelihoods of these women. Ministries responsible for Fisheries, Gender, and Social Protection should consider implementing food distribution programmes during the closed fishing season and urban gardening initiatives to improve access to nutritious foods. Community-based education programmes are essential to raise awareness of balanced diets and the importance of addressing both macronutrient and micronutrient needs.

9.3 Strengths and Weaknesses of the Study

One major strength is the large and diverse sample of women shellfishers across three distinct estuarine sites in Ghana (Densu, Whin, and Narkwa Lagoon). This diversity enhances the generalizability of the findings to this population. Additionally, this study is one of the first in Ghana, and potentially in Africa, to analyse the mineral content of oysters and assess their contribution to dietary intake for women shellfishers. This data is vital for understanding the role of oysters in addressing micronutrient deficiencies. The study also employed two non-consecutive days 24-hour dietary recalls, which provided detailed and reliable information on participants' food consumption and nutrient adequacy. By focusing on women shellfishers, a vulnerable and under-researched group, the study offers valuable insights into their nutritional status in the context of food security and public health. Furthermore, the study assessed the potential health risks associated with oyster consumption, such as contamination from heavy metals, providing a balanced perspective on both the nutritional benefits and potential risks of oyster consumption.

However, there were some limitations. The cross-sectional design of the study limits its ability to establish causal relationships between variables, meaning that the associations observed between factors like nutrient intake and health outcomes may not imply causation. Additionally, the reliance on self-reported dietary intake and other variables introduces the potential for recall bias, which could affect the accuracy of the dietary data, particularly in estimating habitual consumption. While two non-consecutive days 24-hour dietary recalls were used, the exclusion of a weekend day may have further limited the accuracy in capturing typical dietary patterns, as eating habits often vary over weekends. Moreover, the smaller-than-expected sample size from the Whin estuarine site, with only 91.3% of the estimated participants available for recruitment, could have

reduced the statistical power of the study, potentially affecting the ability to detect significant associations in some models.

9.4 Recommendations

Based on the findings, the study offers the following recommendations:

1. The study observed a high prevalence of overweight and obesity among women, underscoring a significant public health concern. It is therefore imperative for public health services in health facilities to incorporate obesity prevention and management into reproductive health services, particularly considering the cultural context and gender disparities in physical activity among Ghanaian adults.
2. Additionally, the study found high prevalence of food insecurity within shellfishing households. Consequently, ongoing sustainability practices for mangrove and estuarine ecosystems, such as the pilot oyster aquaculture in the Densu estuary, should be scaled up to enhance oyster yield. Furthermore, there is a pressing need for local government and the Ministry of Gender and Social Welfare to implement gender-sensitive social protection measures, including livelihood support services for coastal women.
3. Available information regarding oysters-mineral composition can be leveraged to enhance advocacy efforts aimed at promoting oyster consumption. Given that the levels of heavy metals are below regulatory limits and pose no threat to health due to the abundance of selenium, the government and its partners should intensify their efforts to implement mercury-free alternative mining practices to ensure the safety of oyster consumption.
4. Lastly, even though oyster consumption contributes approximately 20% of total iron intake, it remains low. Therefore, further studies employing qualitative methods are

necessary to understand the underlying reasons for the low consumption among women in the oyster value chain. Additionally, a comprehensive approach is required to effectively reduce the risk of anaemia among women of reproductive age, extending beyond the mere promotion of oyster consumption.

9.5 Original contribution to knowledge

- This study presents the first comprehensive data on the mineral composition of oysters consumed by women shellfishers in Ghana, including detailed values for essential micronutrients such as iron and zinc.
- It offers novel findings into the nutritional status of an under-researched population, specifically women shellfishers, within the context of food insecurity, gendered livelihoods, and public health.
- The study is among the first in Ghana, and possibly in West Africa, to analyse both the nutritional benefits and the potential health risks associated with oyster consumption, particularly concerning heavy metal contamination (e.g., arsenic, cadmium, and lead).
- By quantifying the contribution of oyster consumption to dietary iron and zinc intake, the study highlights the dual role that oysters play as both a nutritional resource and a source of livelihood for women in estuarine communities.
- The findings provide evidence-based recommendations for policymakers and development partners, supporting strategies to promote safe oyster consumption, strengthen food-based interventions, and empower women's livelihoods within coastal food systems.

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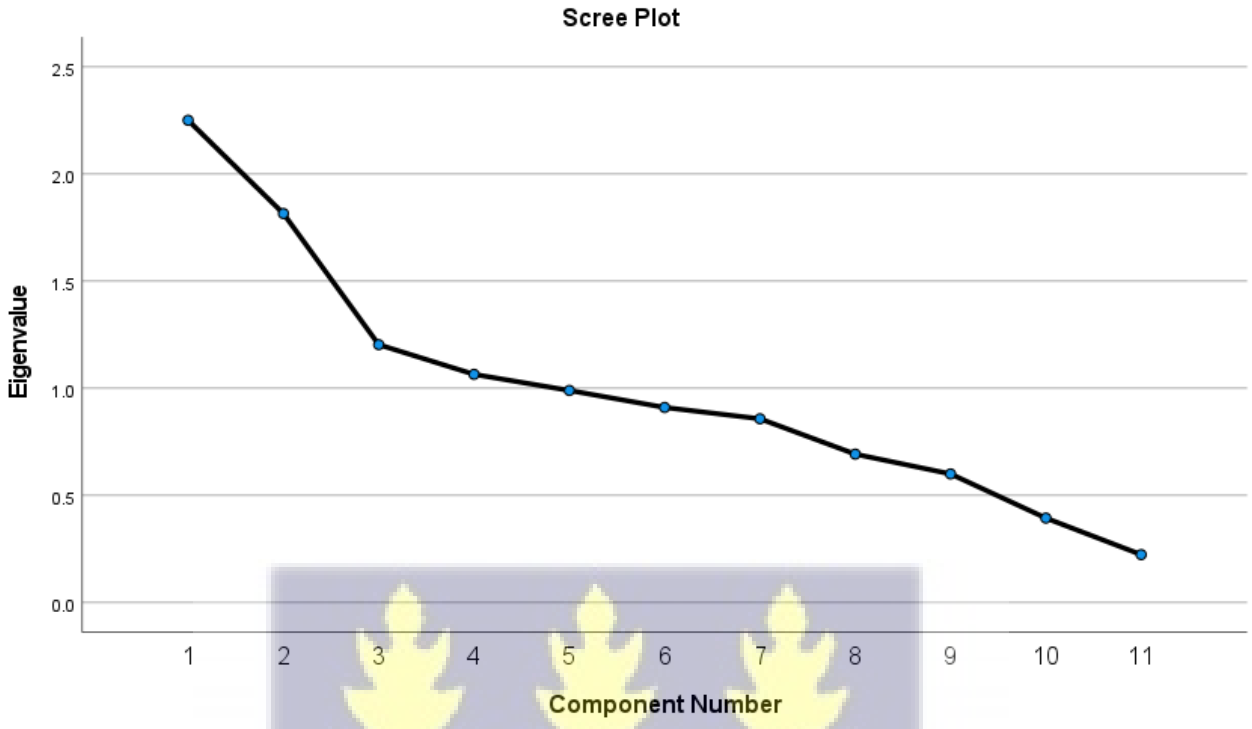
APPENDIX 1: SUPPLEMENTARY SHEETS

Supplementary Sheet 1: food groups classification

Food groups	Descriptions	Frequency of food items consumed as a full meal or snack within 48 hrs
1. Grains (Cereals, tubers & roots products)	Examples: rice-water, rice, wheat, oats, barley, bread, pasta, oblayo, koko, banku, kenkey, akple, Spaghetti/macaroni/indomie, ampesi *(including yam, mpotompoto, cocoyam, plantain, and cassava), jollof,* kokonte/gari *(soakings, eba, etc.), fufu,* biscuits, roasted or boiled corn, etc.	
2. Vegetables	Examples: root vegetables, legumes (beans, beans stew, groundnut), starchy vegetables: squash, *cabbage, carrots, pepper, cucumber, wild leaves: Kontomire, aleefu, and ayoyo*	
3. Fruits	Examples: Apples, oranges, bananas, berries, watermelon, apple, grapes, coconut, avocado, including wild sources, mangoes, papayas, pineapples, guavas, fruit juice (ceres, pure heaven, don simone, kalyppo, etc.)	
4. Dairy & dairy products	Examples: Milk, yogurt, cheese, wagashie, burikina, & tofu	
5. Protein Foods	Examples: flesh meat (beef, pork, lamb), poultry (chicken, turkey), fish and seafood (crabs, oysters, snails, & periwinkles) & eggs.	
6. Fats and Oils	Examples: butter, margarine, & oils	
7. Sweets and Sugars	Examples: Sugar & honey	
8. Beverages	Examples: tea, coffee, juices, soft drinks, alcoholic beverages, *milo, this way, and cowbell drinks all types, sobolo, asana, ice-kenkey, and fresh taste, beers, wine, , rasta, Guinness, vita, beta, palm wine, pito, akpetashie blue jaean, 5star, rush, etc*	
9. Discretionary foods	Examples: cakes, pastries, fried foods, sweetened beverages, snacks, koose, *meat pie, chips, buff loaf, dough nut, fried yam, fried plantain, fried potatoe, fried rice* & sausage	
10. Mixed Dishes	Examples: stews (garden egg, okro, tomatoe, palava sauce), and soups (groundnut, palm nut, light & okro) etc.	
11. Condiments and spices	Examples: shito, pepper sauce,	

Note: Waakye was scored for both group 1 and 2.

Supplementary Sheet 2: Scree plot from the principal component analysis



Supplementary Sheet 3: Structure Matrix: Factor loading of food items

Food items	Dietary Patterns	
	Energy-dense	Nutrient-rich
Grains & tubers	0.799	
Dairy and dairy products	0.718	
Sugars	0.650	
Beverages	0.520	
Mixed Dishes		0.865
Protein Foods	0.363	0.690
Condiments and Spices		-0.555
Fruits		0.361
Discretionary items		-0.312
Variations	20.5%	16.5%

Supplementary Sheet 4: Recovery rates

Certified mass fraction (dry basis) and measured concentration of trace metals in marine iota (Clam, *Gafrarium tumidum*) sample, certified reference material IAEA 461

Analyte	Certified value (mg/kg)	Measured value (mg/kg)	% Recoveries
Mn	333±20.0	330.2±20.4	100.3
Cu	26.1±2.00	23.51±2.52	100.8
Co	4.78±0.60	4.601±0.50	92.6
Cr	27.0±2.4	27.22±1.60	98.6
Cd	0.569±0.040	0.511±0.042	98.0
Pb	25.8±1.70	25.84±2.29	99.0
Ni	106±8.0	107.4±4.47	98.8
Hg	0.390±0.04	0.391±0.04	99.9
Fe	2600±220	2679.3±178.7	101.1
Zn	156.0±11	159.9±11.17	99.9
Ca	9270±900	9136±912.3	101.7

IAEA – International Atomic Energy Agency

APPENDIX 2: ETHICAL CLEARANCE

GHANA HEALTH SERVICE ETHICS REVIEW COMMITTEE

In case of reply the number and date of this Letter should be quoted.

My Ref. GHS/RDD/ERC/Admin/App/21/057
Your Ref. No.

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Ghana Health Service
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18th February, 2021

Dr. Seth Adu-Afarwuah
University of Ghana
Department of Nutrition and Food Science
P. O. Box LG 134
Legon, Ghana

The Ghana Health Service Ethics Review Committee has reviewed and given approval for the implementation of your Study Protocol.

GHS-ERC Number	**GHS-ERC 015/12/20**
Study Title	Food Security, Dietary Intakes and Anemia Prevalence among Women Shell Fishers in Selected Communities in Ghana.
Approval Date	18th February, 2021
Expiry Date	17th February, 2022
GHS-ERC Decision	**Approved**

This approval requires the following from the Principal Investigator

- Submission of a yearly progress report of the study to the Ethics Review Committee (ERC)
- Renewal of ethical approval if the study lasts for more than 12 months.
- Reporting of all serious adverse events related to this study to the ERC within three days verbally and seven days in writing.
- Submission of a final report after completion of the study.
- Informing ERC if study cannot be implemented or is discontinued and reasons why
- Informing the ERC and your sponsor (where applicable) before any publication of the research findings.

You are kindly advised to adhere to the national guidelines or protocols on the prevention of COVID -19

Please note that any modification of the study without ERC approval of the amendment is invalid.

The ERC may observe or cause to be observed procedures and records of the study during and after implementation.

Kindly quote the protocol identification number in all future correspondence in relation to this approved protocol

SIGNED.....
Dr. Cynthia Bannerman
(GHS-ERC Chairperson)

Cc: The Director, Research & Development Division, Ghana Health Service, Accra

APPENDIX 3: QUESTIONNAIRE

Women Shellfishers Sociodemographic Questionnaire

Name of this woman (for purpose of the repeated 24 hr recall): _____	Participant ID ☐☐	
	Interviewer number ☐☐	

I would first like to ask you some questions about yourself.

IN WHAT MONTH AND YEAR WERE YOU BORN?	Month ☐☐ Year ☐☐☐☐			Don't know, enter '99' or '9999'
HOW OLD ARE YOU? *PROBE:* **HOW OLD WERE YOU AT YOUR LAST BIRTHDAY?** *COMPARE MONTH AND YEAR OF BIRTH AND STATED AGE; CORRECT ONE IF NECESSARY*	Age ☐☐ (in completed years) (enter '99' if unknown)			
HAVE YOU EVER ATTENDED SCHOOL?	Yes No Don't know		1 2 9	->NEXT Q -> Q11 -> Q11
WHAT IS THE HIGHEST LEVEL OF SCHOOL YOU ATTENDED? **HOW MANY YEARS AT THIS LEVEL DID YOU COMPLETE?**		Circle code	# years completed	DK
	Kindergarten	0	0 1 2 3	9
	Primary	1 9	0 1 2 3 4 5 6	
	JSS-Junior Secondary	2	0 1 2 3	9
	SSS-Senior Secondary	3	0 1 2 3	9
	Vocational/ commercial/ nursing/ technical/ teaching	4	0 1 2 3	9
	Tertiary/college/univ	5	0 1 2 3 4 5 6	9
	Don't know	9		
NOW I WOULD LIKE YOU TO READ THIS SENTENCE TO ME. *SHOW SENTENCE ON THE CARD TO THE RESPONDENT.* *IF RESPONDENT CANNOT READ WHOLE SENTENCE, PROBE:* **CAN YOU READ PART OF THE SENTENCE TO ME?**	Cannot read at all Able only to read only parts of sentence Able to read whole sentence No sentence in required language (specify)_____ Blind, mute, visually/speech impaired		1 2 3 4 5	

What is your marital status now?	Never married, never lived with a man 1 Currently married 2 Living with a man, but not married 3 Divorced 4 Separated 5 Widowed 6	
As you know, some women take up jobs for which they are paid in cash or kind. Others sell things, have a small business or work on the family farm or in the family business. In the last seven days, have you done any of these things or any other work?	Yes 1 No 2	-> Next Q -> Q14
WHAT IS YOUR JOB OUTSIDE THE HOME?	No job 0 Unskilled labor 1 Skilled labor 2 Agriculture 3 Shop or office 4 Own business 5 Professional 6 Other (specify: _____) 88 Don't know 99	
In the last 24 hours, how many cigarettes did you smoke?	Number ☐☐	
ARE YOU PREGNANT NOW?	Yes 1 No 2 Unsure/ don't know 9	-> Next Q -> Q17 -> Q17
HOW MANY MONTHS PREGNANT ARE YOU?	Number of months ☐☐	
HOW MANY TIMES, IN TOTAL, HAVE YOU BEEN PREGNANT? *IF PREGNANT NOW, INCLUDE THIS PREGNANCY.* *IF NEVER PREGNANT, ENTER "00".* *IF RESPONDENT DOES NOT KNOW, CIRCLE "99".*	Number of times ……. ☐☐ Don't know 99	00->Q22
DURING YOUR LAST PREGNANCY, DID YOU TAKE IRON OR FOLIC ACID SUPPLEMENTS FOR 90 DAYS OR MORE?	Yes 1 No 2 Unsure/ don't know 9	
Following your last pregnancy (i.e. after delivery), did you take any vitamin A capsules? *Show vitamin A capsule.*	Yes 1 No 2 Not sure if it was vitamin A 9	
HOW MANY TIMES, IN TOTAL, HAVE YOU GIVEN BIRTH TO A BABY? *INCLUDE STILL BIRTHS AND LIVE BIRTHS*	Number of times ☐☐	00->Q22
Are you currently breastfeeding a child?	Yes 1 No 2	

POVERTY PROBABILITY INDEX

Indicators	Responses	Points (National Poverty Line)
1. In which region does the household live?	A. Western	17
	B. Central	25
	C. Greater Accra	25
	D. Volta	10
	E. Eastern	29
	F. Ashanti	16
	G. Brong Ahafo	14
	H. Northern	1
	I. Upper East	9
	J. Upper West	0
2. How many members are there in the household?	A. One to four	24
	B. Five to seven	5
	C. Eight or more	0
3. In the past month, have you purchased any chicken eggs (fresh or single)?	A. Yes	4
	B. No	0
4. In the past month, have you purchased any raw or corned beef?	A. Yes	9
	B. No	0
5. What is the main construction material used for the outer wall?	A. Mud/mud bricks/earth	0
	B. Other	0
6. What is the main fuel used by the household for cooking?	A. Wood/ crop residue/sawdust/ animal waste	0
	B. Other	9
7. Does any member of the household own a gas stove?	A. Yes	14
	B. No	0
8. Does any member of the household own a refrigerator?	A. Yes	7
	B. No	0
9. Does any member of the household own a fan?	A. Yes	2
	B. No	0
10. Does any member of the household own a television?	A. Yes	3
	B. No	0

I would next like to ask you some questions about your household.

HOW MANY MEMBERS ARE THERE IN YOUR HOUSEHOLD?	Number	☐☐	
In the past month, have you purchased any chicken eggs (fresh or single)?	Yes No Don't know	1 2 99	
In the past month, have you purchased any raw or corned beef?	Yes No Don't know	1 2 99	
What is the main construction material used for the outer wall of your house?	Mud/mud bricks/earth.. Other Don't know	1 2 99	
What is the main fuel used by the household for cooking?	Wood/crop residue/sawdust/ animal waste.. Other	1 2	

	Don't know	99	
Does any member of the household own a gas stove?	Yes No Don't know	1 2 99	
Does any member of the household own a refrigerator?	Yes No Don't know	1 2 99	
Does any member of the household own a fan?	Yes No Don't know	1 2 99	
Does any member of the household own a television?	Yes No Don't know	1 2 99	

ANEMIA MEASUREMENT

Now we would like to do a fingerpick to measure anemia.

Hemoglobin concentration	Hb (g/dL) ☐☐.☐	

ANTHROPOMETRIC MEASUREMENTS

Woman's weight	Kilograms (kg) ☐☐☐.☐	
Woman's height	Centimeters (cm) ☐☐☐.☐	
Reason why weight or height measurement missing	Disabled, cannot stand on scale 1 Disabled, cannot measure height 2 Uncooperative or uncontrollable 3 Other (specify) _____ 8 Refused 9	

Date of data collection	☐☐/☐☐/☐☐ Day Month Year
Final result of woman data collection	(enter code from below) ☐

FINAL RESULT CODES:	
Completed interview and accepted participation in blood collection 1	Refused interview and all data collection 3
Completed interview and refused participation in blood collection 2	Woman not home or not available 4
	Other (specify) _____ 8

Comments about data collection with this woman:

SECTION E: HOUSEHOLD DIETARY DIVERSITY

Please describe the foods (meals and snacks) that were consumed by all the household members yesterday during the day and night. Start with the first food eaten in the morning. *(Consider foods eaten by **any member of the household**, and **exclude** foods purchased **and** eaten outside of the home]. Write down all food and drinks mentioned by the respondent. When the respondent has finished, probe for meals and snacks not mentioned.*
Number of adults (≥ 18 years) joining the meals yesterday: ____Number of children (< 18 years) joining the meals yesterday: ____

Breakfast	Snack	Lunch	Snack	Dinner	Snack

When the respondent recall is complete, fill in the food groups based on the information recorded above. For any food groups not mentioned, ask the respondent if a food item from this group was consumed.

	Food group	Examples	Response
1	CEREALS	maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, noodles, spaghetti, porridge or other grain products) + insert local foods e.g. ugali, porridge or pastes or other locally available grains	___ yes (1) ___ no (0)
2	VITAMIN A RICH VEGETABLES AND TUBERS	pumpkin, carrots, squash, or sweet potatoes that are orange inside + other locally available vitamin-A rich vegetables (e.g. red sweet pepper)	___ yes (1) ___ no (0)
3	WHITE TUBERS & ROOTS	white potatoes, white yams, white cassava, or other foods made from roots	___ yes (1) ___ no (0)
4	DARK GREEN LEAFY VEGETABLES	dark green/leafy vegetables, including wild ones + locally available vitamin-A rich leaves such as amaranth, cassava leaves, kale, spinach etc.	___ yes (1) ___ no (0)
5	OTHER VEGETABLES	other vegetables (e.g. tomato, onion, eggplant) , including wild vegetables	___ yes (1) ___ no (0)
6	VITAMIN A RICH FRUITS	ripe mangoes, cantaloupe, apricots (fresh or dried), ripe papaya, dried peaches + other locally available vitamin A-rich fruits	___ yes (1) ___ no (0)
7	OTHER FRUITS	other fruits, including wild fruits	___ yes (1) ___ no (0)
8	ORGAN MEAT (IRONRICH)	liver, kidney, heart or other organ meats or blood-based foods	___ yes (1) ___ no (0)
9	FLESH MEATS	beef, pork, lamb, goat, rabbit, wild game, chicken, duck, or other birds	___ yes (1) ___ no (0)
10	EGGS	chicken, duck, guinea hen or any other egg	___ yes (1) ___ no (0)
11	FISH	fresh or dried fish or shellfish	___ yes (1) ___ no (0)
12	LEGUMES, NUTS & SEEDS	beans, peas, lentils, nuts, seeds or foods made from these	___ yes (1) ___ no (0)
13	MILK AND MILK PRODUCTS	milk, cheese, yogurt or other milk products	___ yes (1) ___ no (0)

	Food group	Examples	Response
14	OILS & FATS	oil, fats or butter added to food or used for cooking	___ yes (1) ___ no (0)
15	SWEETS	sugar, honey, sweetened soda or sugary foods such as chocolates, candies, cookies and cakes	___ yes (1) ___ no (0)
16	SPICES, CONDIMENTS, BEVERAGES	spices(black pepper, salt), condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages OR local examples	___ yes (1) ___ no (0)
17	Sugarcane		___ yes (1) ___ no (0)

Minimum Dietary Diversity-Women (MDD-W)

Participant ID: _____

Date: _____

Enumerator: *Now I'd like to ask you to describe everything that you ate or drank yesterday during the day or night, whether you ate it at home or anywhere else. Please include all foods and drinks, any snacks or small meals, as well as any main meals. Remember to include all foods you may have eaten while preparing meals or preparing food for others. Please also include food you ate even if it was eaten elsewhere, away from your home.*

1) Let's start with the first food or drink consumed yesterday. Did you have anything to eat or drink when you woke?
    a. If yes, what?
    b. Anything else?

2) Did you have anything to eat or drink later in the morning?
    a. If yes, what?
    b. Anything else?

3) Did you eat or drink anything at mid-day?
    a. If yes, what?
    b. Anything else?

4) Did you have anything to eat or drink during the afternoon?
    a. If yes, what?

b. Anything else?

5) Did you have anything to eat in the evening?
   a. If yes, what?
   b. Anything else?

6) Did you have anything else to eat or drink in the evening before going to bed or during the night?
   a. If yes, what?
   b. Anything else?

Note: *For each eating episode, after the respondent mentions foods and drinks, probe to ask if she ate or drank anything else. Continue probing until she says "no, nothing else". If the respondent mentions a mixed dish like a soup or stew, ask for all the ingredients in the mixed dish. For mixed dishes where it is possible to pick out ingredients or consume only broth, ask if she herself ate each ingredient or if she only had the broth. Continue to probe about ingredients until she says "nothing else."*
As the respondent recalls foods and drinks, mark the corresponding item in the "Description/ examples to be adapted" column and mark '1' in the response column for that row on the questionnaire. If more than one item in a row is mentioned, mark each item. If the same food or drink is mentioned more than once, you do not need to mark it again after the first time.

Required – Rows A–N (14 rows) will be aggregated during analysis into the ten MDD-W food groups			
	Food categories	**Description/examples to be adapted** Consult **Appendix 2** and replace the example foods below with items commonly consumed in the survey area(s).	**Consumed** Yes = 1 No= 0
A	**Foods made from grains**	*Porridge, bread, rice, pasta/noodles or other foods made from grains*	___yes (1) ___no (0)
B	**White roots and tubers and plantains**	*White potatoes, white yams, manioc/cassava/yucca, cocoyam, taro or any other foods made from white-fleshed roots or tubers, or plantains*	___yes (1) ___no (0)
C	**Pulses (beans, peas and lentils)**	*Mature beans or peas (fresh or dried seed), lentils or bean/pea products, including hummus, tofu and tempeh*	___yes (1) ___no (0)
D	**Nuts and seeds**	*Any tree nut, groundnut/peanut or certain seeds, or nut/seed "butters" or pastes*	___yes (1) ___no (0)
E	**Milk and milk products**	*Milk, cheese, yoghurt or other milk products but NOT including butter, ice cream, cream or sour cream*	___yes (1) ___no (0)
F	**Organ meat**	*Liver, kidney, heart or other organ meats or blood-based foods, including from wild game*	___yes (1) ___no (0)
G	**Meat and poultry**	*Beef, pork, lamb, goat, rabbit, wild game meat, chicken, duck or other bird*	___yes (1) ___no (0)
H	**Fish and seafood**	*Fresh or dried fish, shellfish or seafood*	___yes (1) ___no (0)
I	**Eggs**	*Eggs from poultry or any other bird*	___yes (1) ___no (0)
J	**Dark green leafy vegetables**	*List examples of any medium-to-dark green leafy vegetables, including wild/foraged leaves*	___yes (1) ___no (0)
K	**Vitamin A-rich vegetables, roots and tubers**	*Pumpkin, carrots, squash or sweet potatoes that are yellow or orange inside (see **Appendix 2** for other less-common vitamin A-rich vegetables)*	___yes (1) ___no (0)
L	**Vitamin A-rich fruits**	*Ripe mango, ripe papaya (see **Appendix 2** for other less-common vitamin A-rich fruits)*	___yes (1) ___no (0)
M	**Other vegetables**	*List examples of any other vegetables*	___yes (1) ___no (0)
N	**Other fruits**	*List examples of any other fruits*	___yes (1) ___no (0)

24 HR Recall Sheet

1.1. Respondent ID ..... ……...

1.2. Date of visit: .....|___|___| |___|___| 20 |___|___ dd/ mo./yr.

1.3. Day Food Eaten .....……..…… |___|

[1] Monday [2] Tuesday [3] Wednesday [4] Thursday [5] Friday [6] Saturday [7] Sunday

"I am now going to start the 24-hour dietary recall. Could you please tell me everything you ate and drank yesterday including main meals, snacks, things shared by friends or other members of the community and anything eaten during the night. Remember by starting from the first thing you ate or drank in the morning and continuing through the day until the last thing you ate in the evening or night. It may also help you to remember if you think about activities you did yesterday starting in the morning until the end of the day. Give as much detail as possible, more detail is better"

Meal Time	Description of Food/beverage consumed (List all foods or a combination food)	Source of food	Preparation method	Estimated quantity (food models, measure)	Estimated quantity (g)

Household Food Insecurity Access Scale

No	Question	Response Options	Code
1.	In the past four weeks, did you worry that your household would not have enough food?	0 = No (skip to Q2) 1=Yes	….|___|
1.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	….|___|
2.	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?	0 = No (skip to Q3) 1=Yes	….|___|
2.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	….|___|
3.	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?	0 = No (skip to Q4) 1 = Yes	….|___|
3.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	….|___|
4.	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?	0 = No (skip to Q5) 1 = Yes	….|___|
4.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	….|___|

No	Question	Response Options	CODE
5.	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?	0 = No (skip to Q6) 1 = Yes	....|___|
5.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	....|___|
6.	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was not enough food?	0 = No (skip to Q7) 1 = Yes	....|___|
6.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	....|___|
7.	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?	0 = No (skip to Q8) 1 = Yes	....|___|
7.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	....|___|
8.	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?	0 = No (skip to Q9) 1 = Yes	....|___|
8.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	....|___|
9.	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	0 = No (questionnaire is finished) 1 = Yes	....|___|

No	Question	Response Options	CODE
9.a	How often did this happen?	1 = Rarely (once or twice in the past four weeks) 2 = Sometimes (three to ten times in the past four weeks) 3 = Often (more than ten times in the past four weeks)	....|___|

Oyster Sampling Sheet

Region	Estuary	Harvesting site	Sample quota	Code