



The effect of edible insects on the colour and nutritional value of maize porridges.

By

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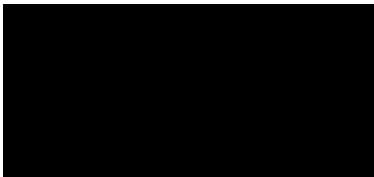
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As the candidate's supervisor, I have approved this thesis for submission.



Supervisor

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PREFACE

The candidate completed the Research Foundation for this thesis while based in the Discipline of Biological Sciences, School of Life Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Westville Campus, South Africa. The National Research Foundation financially supported the research.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.



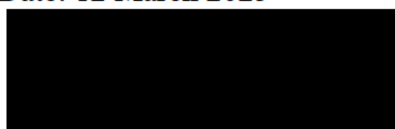
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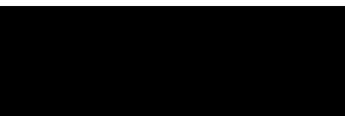
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DECLARATION: PLAGIARISM

I, Sindiswa Zondo, declare that:

- (i) The research reported in this thesis, except where otherwise indicated or acknowledged, is my original work.
- (ii) This thesis has not been submitted in full or in part for any degree or examination to any other university.
- (iii) This thesis does not contain other persons' data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons.
- (iv) This thesis does not contain other persons' writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
 - a) Their words have been rewritten, but the general information attributed to them has been referenced.
 - b) Where their exact words have been used, their writing has been placed inside quotation marks and referenced.
- (v) Where I have used material for which publications followed, I have indicated in detail my role in the work.
- (vi) This thesis is primarily a collection of material, prepared by me, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included.
- (vii) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source is detailed in the thesis and the References sections.



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DECLARATION 2: CONFERENCE PROCEEDINGS

Zondo, S. Hlongwane, T.Z. Munyai, T.C. Slotow, R. Siwela, M. Nutritional value of food products fortified with edible insects: A Systematic Review. Midrand, Gauteng. 13th Oppenheimer Research conference. 09-11 October 2024. Poster presentation.

Zondo, S. Hlongwane, T.Z. Munyai, T.C. Slotow, R. Siwela, M. Effect of insect meal on colour and nutritional value of thin and crumbly (uphuthu) maize meal porridges supplemented with edible insects commonly found in South Africa. Postgraduate Research and Innovative Symposium, Durban. 29-30 October 2024. Oral presentation.

Zondo, S. Hlongwane, T.Z. Munyai, T.C. Slotow, R. Siwela, M. Effect of insect meal on colour and nutritional value of thin and crumbly (uphuthu) maize meal porridges supplemented with edible insects commonly found in South Africa. SHEFS-SA symposium. 6 November 2024. Virtual oral presentation.

ABSTRACT

Food and nutrition insecurity are global problems, particularly in Sub-Saharan Africa. The limited access to nutritious food contributes to various forms of malnutrition, including undernutrition, micronutrient deficiencies, obesity, and stunting. Edible insects were recommended by the Food and Agriculture Organisation (FAO) as a cheap and sustainable solution to address food and nutrition insecurities in developing countries because they are high in protein, zinc, iron, and essential amino acids. Therefore, fortifying commonly consumed staple cereal grain food products such as *uphuthu* (crumbly maize meal porridge) and thin maize porridge with edible insects should significantly improve their nutritional value. This study aimed to assess the effect of edible insect meal on the nutritional value and colour of maize porridges. This was done by (1) reviewing and analysing the existing literature on the nutritional value of food products supplemented with edible insects globally (2) determining the effect of insect meal on the colour of thin and crumbly porridges supplemented with edible insects (3) determining the effect of the addition of different insects' meals on proximate composition, mineral, and amino acid profile of thin and crumbly maize porridges.

A search was conducted following the PRISMA guidelines to identify relevant peer-reviewed publications on food products enriched with edible insect meal. Three edible insect types: mopane worm, termite (workers of an unidentified species of genus *Macrotermes*) and caterpillar in an unidentified species of genus *Gynanisa*, were selected and processed into separate insect meals. Each of these was used to supplement thin and crumbly maize porridges at different concentrations. The thin and crumbly porridge samples were prepared using the standard methods, but maize meal was partially substituted with 5% and 10% (w/w) edible insect meals. The systematic review search resulted in 61 eligible papers listing 26 edible insects that were used to supplement 12 different food products across different locations in the world. Bakery products were the most used food products, followed by snacks, whilst roti and soup were the least used food products, supplemented with insects.

Results of the assessment of the edible insect meal on the colour and nutritional value of the maize porridges showed that the thin and crumbly porridge became darker as the concentration of insect meal was increased. A 10% termite meal concentration resulted in the darkest thin and crumbly porridge, followed by 10% mopane worm, whilst 10% of *Gynanisa* caterpillar meal caused the lowest darkening of the thin and crumbly porridges. Supplementing

thin and crumbly porridges with edible insect meals significantly increased their protein, zinc, and iron content compared to the control. The highest protein levels were observed in porridges with 10% termite meal, while the highest zinc and iron content were found in porridges with 10% mopane worm and *Gynanisa* caterpillar, respectively. However, termites caused the most darkening, potentially reducing consumer acceptability. Therefore, the two insect types (mopane worm and *Gynanisa* caterpillar) are suitable candidates for fortifying maize food products without causing unacceptable darkening of the porridges. This increase in nutritional value upon the addition of insect meal indicates that edible insects can play a role in mitigating the risk of malnutrition in rural and resource-poor communities of South Africa, where thin and crumbly maize porridges are popular staple maize food products. Further studies are recommended to evaluate nutrient bioavailability and consumer acceptability of the insect meal-supplemented maize porridges.

DEDICATION

This thesis is dedicated to my number one cheerleader, my late grandmother. I wish you were still alive to celebrate this milestone with me, you will forever be in my heart, I miss you MaZondo. I hope you are proud of me. This one is for you granny.

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CHAPTER 1

Introduction

The population of Africa is expected to reach 1.71 billion by the year 2030 (Mohajan, 2022). This exponential population growth will exacerbate pressure on the food production system, as food production will be required to increase by 55% to sustain Africa's food requirements (FAO, 2009). Currently, the food industry is under pressure from the growing population and the increasing demand for food to sustain it (Schneider et al., 2011). This will also increase the demand for animal protein, which will cause livestock production to expand (Henchion et al., 2021). Livestock production contributes to environmental degradation, as well as water and air pollution. (Zou et al., 2024). It also accounts for 70% of agricultural land use, contributing to resource scarcity with approximately 112 litres of water required to produce 1 kg of protein (Wirsenius et al., 2010; Garnett, 2013; Mondal and Ganguly, 2019). In addition, livestock production accounts for 12-18% of global greenhouse gas emissions, making it a major contributor to global warming and climate change (Garnett, 2013). Given these challenges, cheaper, more sustainable, and more environmentally friendly protein sources are required.

Edible insects have been recommended as a sustainable and environmentally friendly protein alternative (FAO, 2017). They are rich in nutrients such as protein, zinc, iron, vitamins, and essential amino acids (Hlongwane et al., 2020; Lumanlan et al., 2022). In addition, they have low environmental footprints compared to livestock production (Hlongwane et al., 2020; Lumanlan et al., 2022). Edible insects have a high feed-to-protein conversion factor compared to livestock; hence, they use fewer resources to produce the same quality of protein (Kourimska and Adamkova, 2016; Abril et al., 2022). In addition, insect rearing uses less land and fewer resources and emits fewer greenhouse gasses compared to livestock production (Van Huis, 2016). Edible insects can feed on waste and convert it into high-quality protein (Abril et al., 2022). Hence, they have been recommended as protein alternatives. Although entomophagy (the consumption of insects by human beings) is not a new practice, it has declined over the years (Hlongwane et al., 2020). The noted decline is attributed to stigmas, including fear, disgust, and food neophobia (Olivadese and Dindo, 2023). This has necessitated the need for strategic approaches to reintroduce edible insects to people and promote their consumption.

Incorporating edible insects as hidden ingredients into popular but nutrient-deficient food products has been reported to promote consumer acceptance of edible insects. For example, Mazurek et al. (2022) reported increased consumer acceptance of wheat pancakes fortified with mealworms and buffalo worms.

For a food system to be considered sustainable, everyone must have access to a balanced and nutritious diet (Halloran et al., 2018). However, this must be achieved in ways that will not compromise food, environmental, social, and economic sustainability for future generations (Halloran et al., 2018). Food sustainability remains a challenge in developing countries as strategies to address malnutrition such as fortification of commercial food with micronutrients, and dietary diversification, have to some extent failed to mitigate the negative effect of malnutrition in South Africa, as they are not accessible to everyone but only to those who can afford them (Siwela et al., 2020). Meanwhile, people in disadvantaged communities are mostly affected by malnutrition because of poverty and economic barriers that limit their access to nutritious foods rich in protein, fruits, and dairy products (Murarkar et al., 2020; Ndunge Charles et al., 2024). As a result, their diets are predominantly rich in carbohydrates and vegetables with minimal consumption of fruits, dairy products and animal-based protein (Ndunge Charles et al., 2024). This dietary imbalance contributes to food insecurity and increases the risk of various forms of malnutrition, including stunted growth, wasting, micronutrient deficiencies, and obesity due to overreliance on energy-dense but nutrient-poor foods (Sokhela et al., 2023). Addressing these issues requires strategies to improve economic access, promote dietary diversity, and integrate affordable, nutrient-rich food options (edible insects) into local food systems (Ordonez-Araque and Egas-Montenegro, 2021). The South African government implemented strategies such as social grants and school feeding schemes to ensure food and nutrition security at the household level. However, these strategies primarily focused on access to food rather than the nutritional value of the food consumed by people (Simelane et al., 2023).

In developing countries, malnutrition is primarily driven by poor diets (Ndunge Charles et al., 2024). Cereal grain food products (maize meal porridges, magueu, etc.) are a staple food in developing countries however, they are rich in carbohydrates and low in protein and minerals such as zinc, iron, and amino acids. These cereal grain staple foods are consumed in high portions, contributing to double-burden malnutrition. Several studies have focused on the fortification of staple food products with edible insects and their consumer acceptance (Awobusuyi et al., 2020; Cabuk and Yilmaz, 2020). These studies focused mainly on bakery

products such as bread, biscuits, and muffins, while studies on maize meal food products (crumbly porridge, thin porridge, stiff porridge (*pap*), mageu etc.) that are consumed and popular in resource-poor communities of South Africa are limited. Therefore, this study focuses on improving the nutritional value of maize meal staple food products (thin and crumbly porridge) as a strategy to address malnutrition and the utilization of edible insects as a food source. In addition, the fortification of cereal grain food products would contribute to diversifying diets, reducing reliance on conventional animal protein, and promoting environmental sustainability.

Motivation for the Study

Food and nutrition securities are prominent in Southern Africa. Poverty and limited access to nutritious food are the primary causes of food and nutrition insecurities in this region (Govender et al., 2021). Edible insects are an affordable and sustainable alternative because they are high in several nutrients, including protein, minerals, essential amino acids, vitamins, and energy (Hlongwane et al., 2020). In addition, edible insects are widely available in the wild, and farming insects have less environmental impact (Lange and Nakamura, 2021). Therefore, fortifying cereal grain staple foods with edible insects could improve the nutritional value and quality of staple food, which can play a role in combating malnutrition in disadvantaged communities. Supplementing common food products with edible insects would promote their utilization, as several studies have reported that entomophagy is declining in most parts of the world, including Africa (Obopile and Seeletsho, 2013; Batat and Peter, 2020; Hlongwane et al., 2021). Studies have shown that people are more willing to consume edible insects if they are hidden as an ingredient in common food products (Bawa et al., 2020; Mazurek et al., 2022). Therefore, fortifying popular cereal grain food products with edible insects could improve their sensory attributes and mask the insect component, thereby reducing stigmas, including fears, barriers, and discomfort associated with the consumption of edible insects (Bawa et al., 2020). Through this approach, more people might benefit from the nutritional value of edible insects, and this can play an important role in reducing malnutrition, particularly undernutrition, in poor communities.

Problem statement

Food and nutrition insecurity is a serious global issue (FAO et al., 2020). In 2021, 828 million people were reported to face different levels of hunger worldwide, with Africa having 278 million people facing hunger (WHO, 2021). These figures have increased from preCOVID-19 pandemic (2019) by 150 million people (WHO, 2021). The COVID-19 pandemic

significantly impacted global food systems, and many developing countries, including South Africa, have faced serious economic setbacks (Vermeulen et al., 2023). Agyei et al. (2021) and UNICEF (2021) reported that the COVID-19 pandemic resulted in a high staple food price increase across Sub-Saharan Africa. Low-income citizens were greatly affected by these food price increases, as most South African state funds were redirected to COVID-19 pandemic relief efforts, weakening both food and healthcare systems (Bhorat et al., 2021). Furthermore, the rise in unemployment, escalating food, oil, and fuel prices, and the increasing cost of living have worsened poverty, leading to the lack of access to nutritious food in resource-poor communities (Schonfeldt et al., 2024). These factors highlight the urgent need for cheap, sustainable, and nutritious food sources to address food and nutrition insecurity. The fortification of food products with edible insects can play a role in improving and diversifying diets. Therefore, reducing reliance on animal protein and the need to expand livestock production.

Maize products, including thin and crumbly porridge, are primary staple food sources for many black households (Mkhize et al., 2023). However, they have been reported to be nutrient deficient (Msungu et al., 2022). Awobusuyi et al. (2020) suggested that incorporating insect powder in popular and well accepted, but nutrient-deficient staple food products, especially cereal grain foods such as bread, maize (thin and crumbly porridge), sorghum porridges, and beverages (mageu) might increase the acceptability of edible insects and thereby promote their utilization as a food source.

Aim

This study aimed to assess the effect of adding edible insects on the nutritional value and colour of thin and crumbly porridges supplemented with edible insects.

Objectives

- Review and analyse existing literature on the nutritional value of food products supplemented with edible insects globally.
- To determine the effect of insect meal (mopane worm, termites [workers] and *Gynanisa* caterpillar) on the colour of thin and crumbly porridge supplemented with edible insects.
- To determine the effect of insect meal (mopane worm, termites [workers], and *Gynanisa* caterpillar) meal addition on proximate composition, mineral, and amino acid profile on thin and crumbly porridge.

Research questions

- What does the existing literature reveal about the nutritional value and consumer acceptance of food products supplemented with edible insects?
- How does supplementing maize meal with edible insects affect the colour of thin and crumbly porridge?
- What is the effect of supplementing maize meal with different types of edible insects on the nutritional value of thin porridge?
- How does the insect type affect the nutritional value of thin and crumbly porridge?
- What is the effect of adding different concentrations of edible insects on the nutritional value of thin and crumbly porridges?

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CHAPTER 2

Nutritional value of food products fortified with edible insects: A Systematic Review

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Abstract

Food insecurity and malnutrition are critical global issues affecting 691-783 million people. The Food and Agriculture Organisation (FAO) promotes edible insects as a sustainable protein source that can enhance food and nutrition security, particularly in regions like sub-Saharan Africa, where deficiencies in essential nutrients such as zinc and iron are prevalent. Entomophagy is gaining global attention, highlighting the need for innovative and sustainable methods to incorporate edible insects into diets. This review evaluated the effect of edible insects on the nutritional value of popular foods that are deficient in some essential nutrients. A search for peer-reviewed publications on food products enriched with edible insect meal was conducted using Web of Science, Scopus, and Google Scholar. PRISMA guidelines were followed for screening. Publications included primary data on the nutritional value of insect-supplemented foods without restrictions on food types or insect species. The search yielded 61 eligible papers listing 26 insect species used in 12 food products, including bread, biscuits, cookies, porridge, muffins, ice cream, pancakes, cake, meat, snacks, roti, and soup. Food products with edible insect meal contained about double the protein, iron, and zinc compared to controls, but carbohydrate levels dropped by half. Bakery products effectively masked insect sensory properties, boosting consumer acceptability. The findings show that insects enhance food nutrition but can reduce acceptability, which can be improved by masking undesirable

sensory properties with suitable ingredients. Strategies to promote insect consumption should also be developed and implemented. Acceptance was influenced by knowledge of the nutritional benefits and successful masking of undesirable sensory traits.

Introduction

According to the FAO (2009), the global population is expected to surpass 9.6 billion by 2050, necessitating a 70% rise in food production to support the growing population. Population growth will worsen the issues of malnutrition and food insecurity, which are currently serious global problems (Stein, 2009). Malnutrition is linked with acute and persistent hunger when the underlying cause is a lack of a balanced diet rather than a lack of food (Fedele et al., 2020). For example, obesity and being overweight are types of malnutrition (overnutrition) that occur when there is food but no balanced diet (Fedele et al., 2020). Malnutrition (both undernutrition and overnutrition) can cause serious health problems, particularly in pregnant women, lactating women, children, and the elderly (FAO, 2017). In Sub-Saharan Africa, an estimated 149 million children have stunted growth, 45 million are wasted, and 37 million are classified as obese (Smith, 2023). Protein-energy malnutrition (PEM) continues to be a significant public health issue in developing nations, particularly in Africa and Southern Asia, this results in higher rates of morbidity, mortality, stunted growth, and hindered neurobehavioral development in children. (Adegboye, 2022). According to the World Health Organisation (WHO) (2022), undernutrition accounts for around 60% of deaths that occur in children under the age of five years in underdeveloped countries. FAO (2023) reported that 691-783 million people worldwide are faced with different levels of hunger. Out of these, 345 million people are faced with acute hunger and starvation, many of whom live in underdeveloped nations, including Southern Asia and sub-Saharan Africa, where malnutrition is prevalent (Fombong et al., 2017; FAO, 2022). The implementation of strategies to mitigate food and nutrition insecurity is vital in making sure these figures do not persist (Fombong et al., 2017).

Various strategies have been implemented to combat malnutrition in South Africa (Siwela et al., 2020). This involves fortifying commercial foods with essential micronutrients, enhancing them with high-quality protein, vitamins and amino acids and diversifying diets to boost the production of food rich in these nutrients (Siwela et al., 2020). However, these approaches have not been able to combat malnutrition, although they have been in place for some time (Siwela et al., 2020). Their effectiveness in addressing malnutrition remains limited,

as fortified, supplemented, and diversified foods are costly and primarily accessible to those who can afford them (Awobusuyi, 2020). Most of the strategies that have been implemented or suggested are either short-term solutions or are only accessible to households that can afford them. Therefore, long-term, sustainable, innovative approaches must be implemented to address this challenge (Mayer and Pearce, 2023).

The anticipated growth in population will result in an increased demand for conventional protein sources, such as meat, fish, and chicken (Borges et al., 2022). On the other hand, there are environmental concerns about the increased production of conventional protein sources, especially animal-source foods - continuous land clearing and high greenhouse gas emissions are some of the major causes of concern (Henchion et al., 2017; Lynch et al., 2018; Borges et al., 2022; Messina et al., 2023). Red meat production requires more land, is also associated with extensive water use and produces an excessive quantity of greenhouse gases, including carbon dioxide, methane, nitrous oxide, and ammonia, all of which contribute significantly to global warming (Scholtz et al., 2013). In addition, animal-source foods are generally not economically accessible to most communities in developing regions (Khatun et al., 2021). Whereas, relative to animal-sourced foods, insects have a much lower negative impact on the environment (Igual et al., 2021).

The FAO (2012) estimates that by 2025, over 1.8 million people will reside in areas facing freshwater shortages, and two-thirds of the world's population will face challenges due to declining water resources. To minimize the environmental footprint of livestock farming, the FAO (2017) has recommended limiting the reliance on livestock as a primary protein source. Plant-based protein alternatives were found to help address protein shortage and limit the use of traditional (animal-source foods) protein (Estell et al., 2021). However, their digestibility posed a challenge for humans (Estell et al., 2021; Hadi and Brightwell 2021). One of the significant issues with plant-based protein is the low digestion and solubility of plant proteins resulting from the presence of antinutritional compounds (Hadi and Brightwell 2021). Hence, innovative, environmentally friendly, affordable, and sustainable alternatives are urgently required. Thus, FAO (2017) has recommended edible insects as an acceptable protein alternative as they are affordable, environmentally sustainable, high in protein, and of good nutritional value.

Entomophagy is not a new practice; it has been a part of many people's diets worldwide for centuries (Olivadese and Dindo, 2023). However, the practice has declined dramatically

over the years due to the adoption of Western diets to the extent that the younger generations, particularly in urban areas, do not know about the consumption of edible insects (Hlongwane et al., 2021). Fear and discomfort associated with consuming insects have also been listed as among the top reasons for the decline in the practice (Bawa et al., 2018; Akande et al., 2021; Hlongwane et al., 2021). Therefore, there is a need for work to improve consumer acceptability of edible insects and thus promote their utilisation for improved food and nutrition security (Bawa et al., 2018; Gantner et al., 2022; Duku et al., 2023). This review aims to evaluate the effect of enriching common food products with edible insect meal on their nutritional value. The objectives of the review were to (1) study the evidence that supplementing food products with edible insects improves their nutrient content and (2) evaluate published data on consumer perception and acceptance of food products supplemented with edible insects.

Materials and Methods

Search Strategy

The PRISMA guidelines were followed to obtain information about the nutritional value and consumer acceptability of food products fortified with edible insect meal (Tekkouche and Norman, 2011). A literature search was conducted using the Thomson Reuters' Web of Science, Scopus, and Google Scholar databases to search for relevant peer-reviewed publications focused on food products enriched with edible insect meal on all continents. The following search terms were used: "food product enriched with edible insect", "biscuits supplemented with edible insects", "bread supplemented with edible insects", "cookies enriched with edible insects", "ice cream enriched with edible insects", "muffins enriched with edible insect", "porridge enriched with edible insect powder", "cereal products enriched with edible insect powder" and "insect powder food products". These keywords, along their synonyms, were combined using Boolean operators (AND, OR & NOT), including combinations such as "nutritional composition AND/OR nutritional value", "supplemented AND/OR enriched". Additionally, we reviewed the references cited in the selected articles to identify any relevant studies that were not captured in our initial search. We also checked the references in the selected research articles that may be relevant to the current study but did not appear in our search.

Inclusion and exclusion criteria

We included original research articles focusing on the nutritional value and consumer acceptability of food products enriched with edible insect meals. We included papers that were

published before May 2023. There were no restrictions on the type of food products developed with edible insects, the type of insects used, the country of origin of the insects, and the year of publication. Only studies published in English were included. Conference proceedings, editorial material, and technical reports were excluded from the review. Grey literature can vary widely in structure and availability, making it harder to search and evaluate systematically, and making searching and screening of grey literature time-consuming. Additionally, grey literature is often not peer-reviewed, so its credibility and scientific rigour can be questionable.

Data Quality

To evaluate the quality of publications included in this systematic review, we screened each publication based on the following criteria: assessing that all the relevant information such as the author's names, publication, year of publication, article title, and journal information are clearly stated, confirming that they are peer-reviewed, making sure that the journals has a strong reputation in the field, relevance to the current research topic, review the study design and methodology to confirm their scientific standing which includes the sample size and measurement methodology; check to see if any potential biases may affect the study's outcome, such as funder interests; and, lastly, confirm that the studies will yield pertinent data for the current investigation.

Results

A total of 316 relevant peer-reviewed articles were identified from three databases. After reading the title, 35 peer-reviewed articles were eliminated because they were duplicates. From here, full-text reading was done; thereafter, 231 articles were excluded for not meeting the inclusion criteria. After reading the full text, 50 articles were included because they met all inclusion criteria, and the addition of eleven relevant articles were identified through screening the references. In total, 61 relevant articles were included in a review (Figure 2.1).

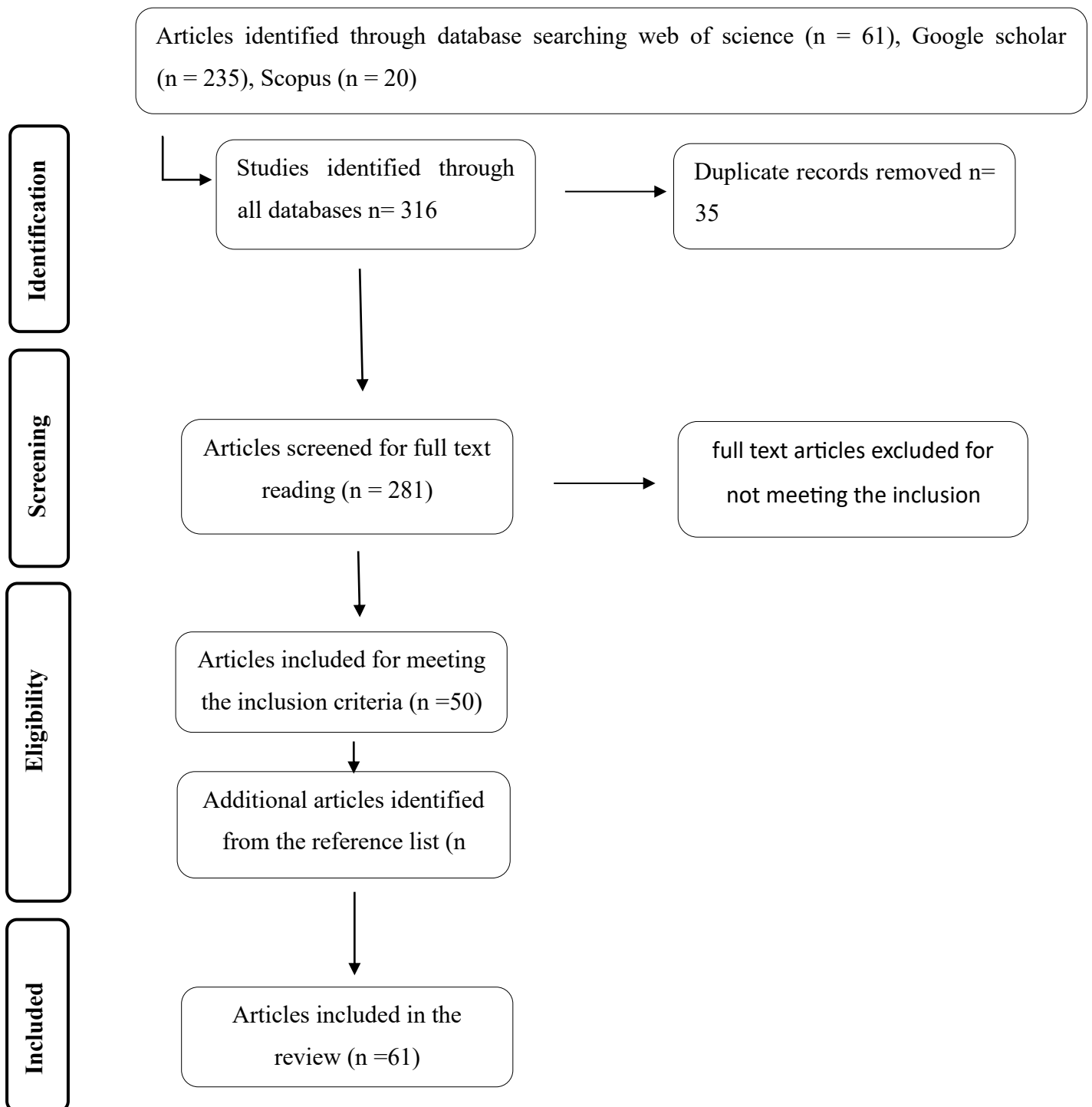


Figure 2.1 Flow chart of the study selection process for a systematic review of the nutritional value and consumer acceptability of food products fortified with edible insects.

The highest number of publications were recorded in 2022, followed by 2020, while the lowest was in 2009 and 2017 (Figure 2).

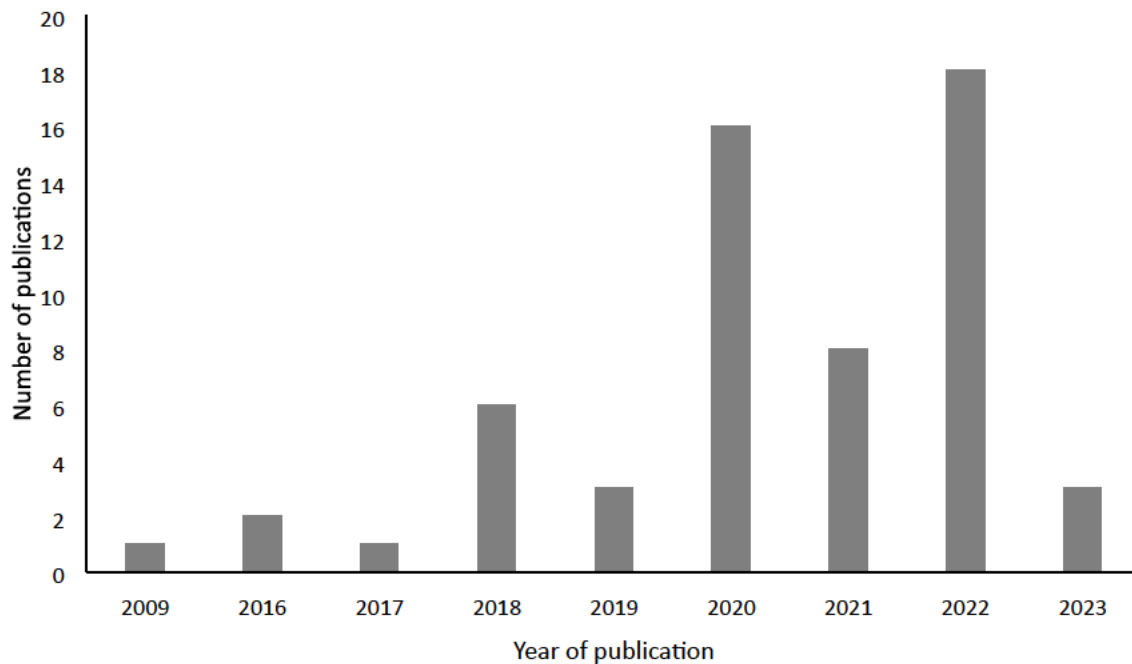


Figure 2.2: Peer-reviewed articles focusing on the nutritional value and consumer acceptability of food products supplemented with edible insects published over the years

A total of 13 food products were used to develop edible insect-enriched food products (Figure 3). Poland had the highest number of publications and food products supplemented with edible insects, followed by Nigeria (Figure 3). Bakery products were the most used food products in both developing and developed countries, followed by snacks, including protein bars, energy bars, puffed-rice snacks, and nut bars, while roti and soup were the least used food products in both developing and developed countries (Figure 3).

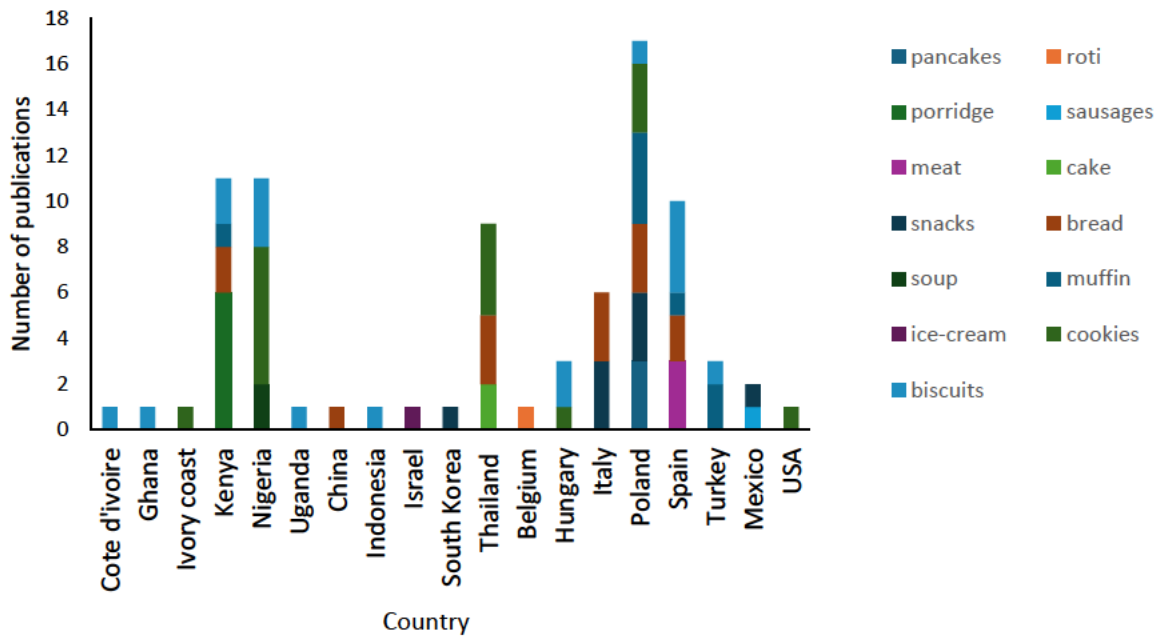


Figure 2.3: Number of publications per food product fortified with edible insects in different countries.

The food products fortified with edible insects showed a significant increase in protein content, which increased with an increasing concentration of edible insects (Appendix 2.1). The highest protein and ash contents were reported in bread supplemented with 20% grasshopper (Appendix 2.1). The food product supplemented with edible insects showed an increase in mineral composition (Appendix 2.2). An increase in zinc and iron was reported in food products supplemented with edible insects, and bakery products supplemented with cricket meal had the highest zinc and iron content (Table 2.2). The control presented the lowest zinc and iron concentrations when compared to the insects incorporated in food products (Table 2.2).

Table 2.1: Nutrient composition (g/100g) and energy (KJ) of foods fortified with edible insects at different levels of fortification (%)

		Level of fortification with insects (%)						
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	Number of publications
Lepidoptera	Protein	13.96±0.40	18.82±0.43	20.78±1.18	23.99±0.32	25.83±0.57	28.2±0.01	4
	Fat	15.46±0.35	16.47±0.33	23.88±0.47	24.51±0.36	25.41±0.16	26.1±0.02	
	Carbohydrates	40.15±0.47	37.30±0.20	49.99±1.17	46.77±0.26	43.40±0.58	34.1 ± 0.06	
	Fibre	4.20±0.03	5.59±0.12	1.47±0.04	1.59±0.07	1.94±0.14	3.8 ± 0.02	
	Ash	0.95±0.07	1.11±0.05	1.14±0.03	0.77±0.16	1.51±0.5	3.8 ± 0.02	
	Energy	293.15±1.86	319.02±1.86	466.6±0.30	473.50±0.60	476.6±1.10	484.12 ± 0.06	
Blattodea	Protein	9.24±0.36	23.39±0.62	21.15±0.24	28.39±0.30	19.55±0.42	21.35±0.26	5
	Fat	13.96±0.30	14.19±0.50	19.93±0.35	21.13±0.41	17.68±0.61	17.01±0.62	
	Carbohydrates	-	-	-	-	-	-	
	Fibre	8.3±0.5	13.2±0.5	10.3±0.4	13.00±0.5	-	-	
	Ash	1.7±0.5	3.5±0.6	4.00±0.5	4.2±0.4	-	-	
	Energy	303.30±3.00	-	322.40±0.14	-	338.10±0.40	358.80±0.71	
Orthoptera	Protein	15.77±1.08	15.99±0.33	21.77±0.58	15.82±0.02	18.91±1.49	22.28±0.28	27
	Fat	17.78±0.68	18.48±0.49	18.19±0.53	28.77±0.28	20.75±0.44	15.46±0.34	
	Carbohydrates	53.24±1.02	35.09±0.76	47.83±0.83	44.97±0.44	39.78±0.90	41.72±0.47	
	Fibre	3.66±0.06	2.71±0.19	7.58±0.65	5.98±0.86	8.76±0.51	5.05±0.19	
	Ash	2.91±0.09	2.58±0.07	3.65±0.01	-	9.48±0.06	1.91±0.66	
	Energy	914.92±4.02	501.61±5.88	997.82±6.95	1389.50±3.43	1316.33±3.02	329.25±4.45	
Coleoptera	Protein	9.48±0.27	18.53±0.44	13.18±0.22	14.63±0.24	16.03±0.33	19.16±0.42	19

Fat	17.9±0.35	16.15±0.33	12.40±0.20	23.77±0.37	17.46±0.39	22.22±0.45
Carbohydrates	57.43±1.11	41.03±1.06	40.46±0.48	40.89±1.13	45.94±0.53	38.85±0.54
Fibre	2.71±0.18	7.56±0.45	2.54±0.17	7.74±0.82	1.96±0.05	5.34±0.01
Ash	1.07±0.11	2.57±0.04	1.18±0.02	0.98±0.03	1.20±0.03	2.00±0.04
Energy	512.20±3.79	1469±11.20	659.95±5.41	501.38±5.23	412.59±1.83	455.52±4.12

Table 2.1: Cont.

		Level of fortification with insects (%)						Number of publications
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Isoptera	Protein	10.00±0.01	14.26±0.17	-	-	-	-	2
	Fat	12.52±0.31	12.62±0.33	-	-	-	-	
	Carbohydrates	56.75±1.63	51.14±3.07	-	-	-	-	
	Fibre	10.34±0.06	12.46±0.20	-	-	-	-	
	Ash	3.15±0.04	3.85±0.15	-	-	-	-	
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Diptera	Protein	12.69±0.60	45.09±0.82	-	-	-	-	1
	Fat	1.19±0.02	35.82±0.66	-	-	-	-	
	Carbohydrates	85.57±0.58	14.84±0.35	-	-	-	-	
	Ash	0.64±0.01	4.25±0.00	-	-	-	-	

(%) percentages are the incorporation rates. (-) means that there are no reports for those incorporation rates. Number of publications: the publications used are listed in Appendix 2.1.

Table 2.2: Comparison of mineral content of food enriched with edible insects

Order	Minerals	Level of fortification with edible insects (%)						Number of publications
		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Lepidoptera	Iron	4.49±0.19	4.6±0.31	4.79±0.04	4.91±0.04	4.98±0.27	-	2
	Zinc (mg)	2.31±0.01	2.90±0.06	3.34±0.13	3.37±0.40	3.40±0.14	9.31±0.02	
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Blattodea	Iron	3.69±0.78	17.47±0.63	30.20±0.39	34.48±0.43	36.85±0.67	43.33±0.93	3
	Zinc (mg)	3.06±0.31	6.91±0.42	8.88±0.38	11.24±0.44	8.6±0.51	12.85±0.74	
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Orthoptera	Iron	5.25±0.16	0.72±0.05	5.65±0.07	37.2±0.08	52.1±0.45	-	7
	Zinc (mg)	7.96±0.05	1.40±0.02	7.99±0.05	28.9±0.02	37.9±0.13	-	
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Coleoptera	Iron	20.77±0.17	135.30±0.01	143.5±0.01	-	-	-	2
	Zinc (mg)	52.15±0.01	363.6±0.02	372.4±0.01	-	-	-	
Order		0%	1-5%	6-10%	11-15%	16-20%	20+%	
Diptera	Iron	12.69±0.06	45.09±0.82	-	-	-	-	1
Order	Zinc (mg)	1.19±0.02	35.82±0.66	-	-	-	-	

(%) percentages are the incorporation rates. (-) means that there are no reports for those incorporation rates. Number of publications: the publications used are listed in Appendix 2.2.

Consumer acceptance

Out of the 62 research papers reviewed, only 12 reported on consumer acceptance. Food products supplemented with edible insects were mostly well-accepted, with recommendations to mask the insects' flavour (Appendix 2.3). Bread, cookies and energy bars were highly accepted, whereas porridge was moderately accepted. Knowledge about the high nutritional value of food products supplemented with edible insects changed the perspective from which the consumers viewed the food products, and they were more willing to try these food products (Appendix 2.3). Most studies (90%) indicated that most consumers were worried about the visibility of edible insect parts in some food products, whereas some were concerned about the colour change in the food products supplemented with edible insects and, most importantly, the masking of the flavour of edible insects (Appendix 2.3).

Discussion

The current review highlights that bakery food products are predominantly utilised for the fortification with edible insects in the development of new food items. Bakery food products are well-accepted worldwide and are considered a staple food in developed countries (Wieczorek et al., 2022). They are a key part of daily diets in developed countries; hence, they were the most studied food products, as most studies were conducted in developed countries. Staple food products that are commonly consumed and accessible to most people in Africa include maize porridges, cassava, soups (egusi soup), and rice were rarely used to develop food products fortified with edible insects (Omotayo et al., 2020). However, most studies conducted in Nigeria, Kenya and Ghana used bakery products instead of staple food products that are commonly consumed in African communities (Adeboye et al., 2016; Akande et al., 2020; Awobusuyi et al., 2020; Dewi et al., 2020; Ouma et al., 2022; Duku et al., 2023; Ogidi et al., 2023). Therefore, studies conducted in developing countries should use staple foods that are commonly consumed and accessible to the majority of people in developing countries, particularly in disadvantaged communities where different forms of malnutrition are prevalent. Our review highlighted an increase in consumer acceptance of foods supplemented with edible insects in both developed and developing countries. This implies that people are more willing to eat insects when their physical characteristics are not visible. Previous studies have reported that incorporating edible insects into value-added food products will increase consumer acceptance and utilization of edible insects (Acosta-Estrada et al., 2021; Garsia-Segovia et al., 2020). The current review showed that most of the studies were conducted in developed countries where the consumption of edible insects is not well accepted because of barriers and

food neophobia, such as fear and disgust associated with eating insects (Olivadese and Dindo, 2023). Therefore, the increase in consumer acceptance of food products supplemented with edible insects in developed countries indicates that people are more willing to try food products supplemented with edible insects because this improves the sensory attributes of edible insects and masks the insect flavour (Adamek et al., 2018; Mazurek et al., 2022). Knowledge about the nutritional value of edible insects positively affected the attitude and willingness to consume food products supplemented with edible insects. This suggests that individuals are becoming more aware of their health and the nutritional value of the food they eat. According to Baker et al. (2022), people are becoming conscious of the nutritional value and quality of the food they consume. Therefore, consumer acceptance of food products supplemented with edible insects is dependent on how they are presented and on knowledge about their nutritional value.

The protein content of food products supplemented with edible insects increased with the increasing concentration of edible insects. Increasing protein content in people's diets will mitigate the prevalence of protein deficiency-related disorders like stunted growth. Proteins are considered a basic nutritional requirement for the human body's regular functioning (Johnson et al., 1999). Sufficient daily protein intake (0.8g-1g per kg of body weight a day) is essential for muscle protein synthesis, as it provides amino acids needed for muscle growth (Wolfe et al., 2008). Hence, the prevalence of stunted growth, wasting and protein energy malnutrition is due to the lack of proteins in people's diets, particularly in childhood, lactating women and elderly people (Endrinikapoulos et al., 2023).

The carbohydrate content of different food products decreased with increasing concentrations of edible insects. According to Ayensu (2018), the decrease in carbohydrate content in food products supplemented with a high concentration of edible insects might be attributed to the decrease in the amount of wheat flour used to produce the same final quantity and an increase in edible insect meal, which is lower in carbohydrates. Carbohydrates are one of the most important macronutrients, and they are broken down into glucose, making them the primary source of energy (Hlongwane et al., 2020; Holesh et al., 2023). In the human body, excess energy is stored as fat in the liver and muscle tissue (Norgon, 1997; Ahmed et al., 2021). Hence, the carbohydrate concentration in the food we eat needs to be carefully balanced to prevent having too much excess energy and fat stored (Sims and Danforth, 1987; Holesh et al., 2023; Zhang et al., 2023). Diets in poor communities mainly consist of carbohydrate-rich starchy food products, which contributes to the prevalence of malnutrition in these communities (Ndunge Charles et al., 2024). Therefore, fortifying those carbohydrate-rich

starchy food products might reduce the consumption of carbohydrate-rich foods, which will play an important role in mitigating the effect of malnutrition. Food products with a low glycemic index are absorbed into the body slowly, resulting in a person being full for longer, hence reducing the risk of obesity, diabetes, and other diabetes-related complications (Sabarathinam, 2023). Therefore, food products higher in simple carbohydrates and with a high glycemic index will result in a high risk of obesity, diabetes and related complications, making it more important to know the type of carbohydrate in the foods we consume (Sabarathinam, 2023). The reduction in the carbohydrate concentrations in foods fortified with edible insects is positive because it reduces the chances of being obese and diabetic, hence promoting healthier food intake.

Food products supplemented with edible insects had higher zinc and iron content when compared to the control. The highest iron and zinc were reported in cookies supplemented with cricket meal. Therefore, in trying to mitigate the prevalence of mineral deficiencies, crickets could be the best edible insects to supplement staple food products for maximum mineral enhancement. Iron and zinc deficiency are common and problematic mineral deficiencies that are prevalent in reproductive-age females and children (Prasad, 2020; Man et al., 2022). Zinc and iron deficiencies give rise to retarded growth, slow wound healing, diarrhoea, and impaired skeletal structures (Shahzad et al., 2014; Prasad, 2020). Most staple foods consumed in developing countries, particularly in disadvantaged communities, do not have sufficient iron and zinc content. Food products that are rich in zinc, including meat, legumes and dairy, are not easily accessible in rural communities because these food products are not readily available in rural areas, and they are sold at inflated prices in local tuckshops (Hambidge and Krebs 2007). Therefore, consuming food products supplemented with edible insects can play an important role in reducing zinc and iron deficiencies worldwide.

Conclusion

Bakery products were the most used food products because they are well accepted worldwide and considered a staple food in developing countries where most of the studies reviewed were conducted. However, more work needs to be done in Africa as there is limited research on African communities' staple foods. Food products supplemented with edible insects were well received and accepted when they were not visible in the food product, and less acceptable organoleptic properties, especially taste, were not detectable. Knowledge about the good nutritional value of the insects also increased their consumer acceptability.

The addition of insect meals in various food products resulted in a significant increase in nutrient content, particularly proteins, zinc, and iron, indicating the potential of edible insects to improve the nutritional value of the food product. Protein, zinc, and iron concentrations increased significantly with an increase in insect incorporation, whereas on the other hand, carbohydrates decreased with an increase in insect meal concentration. Therefore, enriching nutrient-deficient food products with edible insects could play a vital role in mitigating the effects of malnutrition. Thus, edible insects have the potential to be used as an economically and environmentally sustainable strategy for addressing food and nutrition insecurity in developing countries. The formulation of the foods supplemented with insects should be optimised and coupled with strategies that promote the utilisation of insects as a source of food—changing the negative perception of some of the target consumers about insects and nutrition education are some suggested strategies.

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Chapter 3

Effect of insect meal on the colour and nutritional value of thin and crumbly (uphuthu) maize meal porridges supplemented with edible insects commonly found in South Africa

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Abstract

Protein-energy malnutrition (PEM) and mineral deficiencies, particularly iron and zinc, are prevalent in developing countries, including South Africa. To address these issues, the FAO suggested eating edible insects because various types of insects provide different amounts of high-quality protein and other nutrients, like iron, zinc, and some essential amino acids. Unfortunately, edible insects are not readily acceptable to most communities vulnerable to malnutrition because of several factors, including the possible negative effects on the physical and/or sensory quality properties, such as colour. Therefore, this study investigates the effect of partially replacing maize meal with mopane worm, termite, and *Gynanisa* caterpillar meals on the colour and nutritional value of thin and crumbly (uphuthu) porridges. The thin and crumbly porridge samples were prepared using the standard method, but maize meal was partially substituted with 5% and 10% (w/w) edible insect meals. The colour and nutritional value of the porridge samples, as well as the control (100% maize meal), were analysed using standard methods. Thin and crumbly porridge samples darkened with higher concentrations of edible insect meal, especially with termite meal, compared to other insect types. In addition, the nutrients (mainly in terms of protein, amino acids, including essential amino acids and minerals, including iron and zinc) of thin porridge and crumbly porridge increased with increasing concentration of the edible insect meals. The results indicate that edible insects can be used to fortify maize meal products with several nutrients, including protein and minerals

such as zinc and iron, and thereby contribute to addressing nutrient deficiencies prevalent in developing countries like South Africa. However, there may be a need to improve the quality properties of insect-supplemented foods, such as reducing the dark colour imparted by insect meal on the traditionally light maize porridges through manipulation of their ingredient composition.

Introduction

Africa accounts for one-third (approximately 282 million people) of the world's undernourished population (Mohajan, 2021). Mineral deficiency (zinc and iron) and protein energy malnutrition are pressing health problems prevalent in African countries, mostly affecting pregnant women, children under the age of five years, and elderly people (Swanepoel et al., 2018). Currently, in Southern Africa, 27.4% of children under the age of five are stunted, 6% are underweight, 2.5% are wasted, and 13% are micronutrient deficient (Sokhela et al., 2023). Elderly people, pregnant women, and lactating women are no exception; nutrient deficiencies result in anaemia, among other forms of malnutrition, in these groups (Swanepoel et al., 2018). There are several interwoven drivers of malnutrition described above, including poverty and poor, undiversified diets that generally consist of starchy cereal grain staples (Ndunge Charles et al., 2024)

Approximately 80% of the South African population consumes staple foods made from maize meal, including crumbly porridge (known as uphuthu in isiZulu) and thin porridge (regular soft maize porridge) (Rebe et al., 2024). Maize meal products are primarily consumed by black South Africans across urban and rural areas, with a higher prevalence in rural areas and informal settlements (Lauw, 2022). Approximately 55% of South Africans consume maize meal porridge for breakfast, 68% consume crumbly porridge, and 73% consume stiff maize porridge (Rebe et al., 2024). As a result, most people in rural areas and informal settlements may consume maize meal products three times a day (Rebe et al., 2024). Maize meal food products are rich in carbohydrates but low in protein and fats (Amegbor et al., 2022). Additionally, they lack essential nutrients, including essential amino acids (lysine and tryptophan) and micronutrients (Zinc, Iron, and vitamin A), which are vital for the normal functioning of the human body (Goredema Matongera et al., 2021; Amegbor et al., 2022; Colbert, 2023). Therefore, having maize meal products as a primary food source deprives the consumers of a balanced diet. Most low-income households depend primarily on crumbly porridge and pap as their main food source, resulting in diets that are predominately rich in carbohydrates with a low consumption of fruits, dairy products, and animal protein, which

results in a lower intake of iron, protein, and zinc (Amegbor et al., 2022). One of the main causes of malnutrition is a lack of availability to foods high in micronutrients, such as fruits, meat and vegetables (Shetty, 2011).

Edible insects are sustainable and innovative protein alternatives (FAO, 2013; Lisboa et al. (2024). This is due to their high nutritious value, as they are rich in protein, zinc, iron, and essential amino acids (Hlongwane et al., 2020; Hlongwane et al., 2022). In addition, edible insects are environmentally friendly; they emit fewer greenhouse gasses, use fewer resources, and require less land (Lumanlan et al., 2022). Moreover, entomophagy (consumption of insects by humans) is an ancient practice that has been part of human diets for approximately 7000 years (Tang et al., 2019). In certain countries across sub-Saharan Africa and Southern Asia, edible insects are regarded as a delicacy (Olivadese and Dindo, 2023). They are valued for their high nutritional content and are recognised as a healthy food source (Payne et al., 2016; van Huis, 2016; Kourimska and Adamkova, 2016; Hlongwane et al., 2020). Nonetheless, South Africa and other developing countries have seen a sharp drop in the intake of edible insects (Hlongwane et al., 2021). The adoption of Western diets and the discomfort and anxiety associated with eating insects appear to be the main causes of the decline in insect consumption (Hlongwane et al., 2021). Thus, adding edible insects to well-accepted staple food products may enhance their nutritional content and quality while masking the insects' components, possibly boosting consumer acceptance and encouraging their use as food. However, the sensory qualities of these food products may be impacted by the addition of edible insects (Zielinska et al., 2021).

Sensory characteristics such as colour, aroma, texture, and taste play a significant role in the consumer acceptance of food products and greatly influence the decision to eat or avoid some food products (Cabuk and Yilmaz, 2020; Mishyana et al., 2020). Jeesan and Seo (2020) stated that colour plays an important role in food preference. It also affects other senses, as specific food colours are associated with different textures, tastes and aromas. In addition, Khumalo et al. (2011) stated that colour plays a significant role in maize consumption in Africa. For example, white maize is preferred over yellow maize, although yellow maize is more nutritious. Spence et al. (2010) and Huang and Lu, (2015) suggested that the colour of food triggers certain expectations and perceptions, which play an important role in food consumption and acceptance. However, studies have shown that consumers are more willing to consume insects when hidden as an ingredient in common food products such as bread, porridge, and biscuits (Awobusuyi et al., 2020; Akande et al., 2021).

Therefore, this study aimed to evaluate the effect of partially supplementing maize meal with mopane worm, termite, and *Gynanisa* caterpillar meals on the colour and nutritional value of thin porridge and crumbly porridge (uphuthu). By determining the (1) effect of insect meal (mopane worm, *Gynanisa* caterpillar, and termite (workers)) addition on the proximate composition, mineral, and amino acid profile of thin and crumbly porridges, (2) effect of adding edible insects on the colour of thin and crumbly porridges

Materials and Methods

Origin of edible insects

Dried edible insects, i.e., *Gonimbrasia belina* (mopane worm), *Gynanisa* caterpillars, and termites (workers) (Appendix 3.1), were purchased from informal markets in the Vhembe district, Limpopo, South Africa. As part of pre-sale processing, before drying, *Gonimbrasia belina* and *Gynanisa* caterpillars were degutted and dried to increase their shelf life. These insects were selected because they are the most consumed insects in South Africa, and they are highly nutritious (Hlongwane et al., 2021; Hlongwane et al., 2022)

Thin and crumbly (*uphuthu*) porridge production

Before preparing the thin and crumbly porridge, the dried insects were milled using a Hammer mill (model SK1, manufactured by Retsch KG, Haan, Germany). The thin porridge was selected because it is a staple food that is consumed by every age group, from infants (used as a complementary food product) to older people, mostly consumed in the morning for breakfast. The crumbly porridge was selected because it is a traditional starchy staple food that is consumed regularly in KwaZulu-Natal province, South Africa. The reason for having two types of maize porridges was to cover all age groups. The crumbly and thin porridges were prepared following the method described by Pillay et al. (2011). The edible insects (termites, mopane worms and *Gynanisa* caterpillar) were incorporated in the percentages 0% (control), 5%, and 10% for each dish.

Thin porridge preparation

In a saucepan, 2000 ml (8 cups) of water was boiled, and a teaspoon of salt (1g) was added. While waiting for the water to boil, two cups (268g) of maize meal were added to a mixing basin and mixed with 500 ml (2 cups) of tap water to form a paste. The paste was slowly added to the boiling water while continually stirring to avoid lump formation. The mixture was continually whisked until it began to thicken. Thereafter, the heat was lowered and simmered for 20-35 minutes. The same process was followed when supplementing insect meal into thin

porridge, substituting 5% and 10% of the maize meal with edible insect meal (termites, *Gynanisa* caterpillar and mopane worm). Three insect concentrations were replicated three times

Crumbly porridge (*uphuthu*) preparation

In a saucepan, 375 ml of water with a teaspoon of salt was brought to a boil. Two cups (268g) of maize meal were added, and the pan was closed for 2 minutes. Thereafter, the mixture was cooked at medium heat, and the mixture was continuously stirred with a fork until it was soft and crumbly. Once everything was fully combined, the pot was closed for 30 minutes, stirring every 7-10 minutes until cooked. The same process was followed for the insects incorporated into crumbly porridge, substituting 5% and 10% of the maize meal with insect meals (termites, *Gynanisa* caterpillar, and mopane worm). Three insect concentrations were replicated three times.

Colour measurement

Once cooked, the mixture was allowed to cool to $> 5^{\circ}\text{C}$, and samples were collected for the colour analysis. The colourimeter was used, because it is convenient and widely used and provides accurate and quantifiable data on food colour. The CIE tristimulus L, a, and b parameters of porridge supplemented with insect powder were measured using a colorimeter (Colour Flex-Diffuse, Hunter-Lab, s/n: CX2764). The colourimeter functions based on the CIE L^* , a^* , and b^* colour system. The L^* axis represents lightness, ranging from 0 (black) to 100 (white). The a^* axis measures red-green variations, where positive values indicate red, negative values indicate green, and 0 represents neutrality. Similarly, the b^* axis reflects yellow-blue variations, with positive values indicating yellow, negative values indicating blue, and 0 as neutral (Oyenyika et al., 2018). The device was calibrated before use, and the samples were positioned in the sample holder and covered with a Sample Cup Opaque Cover to trap and prevent external light from interfering with the results. Easy Match QC was used to perform numerical calculations on data measured by the Colour Flex. The colour measurement of porridge was determined in duplicate replication; they were also triplicated within each replication. Hence, six replications for each sample. The total colour difference was calculated using the formula below:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where ΔL^* , Δa^* , and Δb^* are differences in the L^* , a^* , and b^* values between the reference sample and the test sample, respectively.

Nutritional value

The nutritional value of thin and crumbly porridge control and thin and crumbly porridge supplemented with mopane worm, *Gynanisa* caterpillar, and termite meals were determined using standard methods. Thin and crumbly porridges were freeze-dried (Edwards, High Vacuum International, Sussex, England), and grounded using a blender to a particle size of ≤ 1 mm. Each food product (thin and crumbly porridge) was triplicated for each treatment (edible insects: mopane worm, *Gynanisa* caterpillar, and termites; at different incorporation rates 0%(control), 5% and 10% incorporation rates). The proximate composition, including moisture, fat, ash, crude fibre, and protein of the insect samples and the thin and crumbly porridges, were assessed using the Association of Official Analytical Chemists (AOAC) Official Method (AOAC, 2003). The AOAC (Association of Official Analytical Chemists) methods were used because they are internationally recognised reference standards. They are validated, peer-reviewed, and standardised protocols used internationally. Additionally, they ensure consistent, comparable results.

Protein content

The protein content of edible insects was analysed in samples of thin and crumbly porridges supplemented with edible insects using a LECO Truspec Nitrogen Analyzer (LECO Corporation, St. Joseph, Michigan, USA). The analysis followed the Association of Official Analytical Chemists (AOAC) Official Method 990.03 (AOAC, 2003). The samples were positioned in a combustion chamber at 950 °C using an autoloader. This was repeated three times (triplicated) for all the food products (thin porridge and crumbly porridge) at different incorporation rates (0%, 5% and 10%) of each edible insect (mopane worm, *Gynanisa* caterpillar and termites). The following equation (AOAC, 2003) was used to calculate the percentage of protein:

$$\% \text{ crude protein} = \% N \times 6.25$$

Ash (total mineral) content

The AOAC Official Method 942.05 (AOAC, 2023) was used to determine the samples' mineral content. After being weighed, the samples spent a full day at 550 °C in a furnace. Following the volatilisation of the organic matter from the samples, the minerals were still present in the

crucibles as an ash residue. The ash content percentage was calculated using the following formula (AOAC, 2003):

$$\% \text{ ash} = \frac{(\text{mass of sample+crucible after ashing})-(\text{mass of pre-dried crucible})}{(\text{mass of sample+crucible})-(\text{mass of pre-dried crucible})} \times 100$$

Fat content

The Soxhlet technique was used to determine the samples' fat content. The analysis was conducted using the Büchi 810 Soxhlet Fat extractor (Büchi, Flawil, Switzerland) following AOAC Official Method 920.39 (AOAC, 2003). The following formula was used to determine the percentage of crude fat after petroleum ether was employed for extraction (AOAC, 2003):

$$\% \text{ crude fat} = \frac{\text{beaker+fat-beaker} \times 100}{\text{sample mass}}$$

Carbohydrate content

The carbohydrate contents were determined by difference (100- moisture + fat +ash + crude fibre + protein)

Gross energy content

Gross energy was determined using a bomb calorimeter (Leco AC500). The initial temperature of the calorimeter (Ti) was recorded before igniting the sample, after which the final temperature (Tf) was noted. The energy content of the sample was then calculated using the formula:

$$\text{Gross energy (Kcal/g)} = (\Delta T \times C_s) - (\text{length of wire burnt} \times W_t \times 1000)$$

where ΔT represents the temperature change (Tf - Ti), W_t is the sample weight, and C_s is the energy equivalent of the bomb system (10,316.2 J/g).

Mineral compositions

The analysis of zinc, iron, phosphorus, calcium, sodium, magnesium, potassium, copper, and manganese was conducted using the Agricultural Laboratory Association of Southern Africa (ALASA) Method 6.1.1 (ALASA, 1998). As part of the procedure, samples were initially freeze-dried using a freeze-dryer (Edwards, High Vacuum International, Sussex, England). They were then ashed in a furnace at 550 °C for 24 hours. Working under a fume extractor, the ashed samples were dissolved in hydrochloric acid (2 ml of 32% (v/v) concentrated HCl), followed by the addition of 25 ml of diluted (diluted at a 1:9 ratio) 32% (v/v) HCl (100 ml of HCl and 900 ml of deionised water). Elemental analysis was performed using an atomic

absorption spectrophotometer. Specifically, calcium and phosphorus concentrations were measured with the Analytik Jena Spekol 1300 spectrophotometer (Analytik Jena AG, Achtung, Germany), zinc was analyzed using the GBC 905AA spectrophotometer (GBC Scientific Equipment Pty Ltd., Dandenong, Victoria, Australia), and iron was quantified with the Varian SpectrAA atomic absorption spectrophotometer (Varian Australia Pty Ltd., Mulgrave, Victoria).

Amino acid profile

After HCl hydrolysis and derivatization amino acids were determined. The method of International Analytical Group (International Analytical Group, 2016). The hydrolysate was filtered using centrifuge tube filters (Corning® Costar® Spin-X tubes, Sigma-Aldrich, St. Louis, MO, USA). A standard detection system comprising a dynode, phosphor, and photomultiplier was utilised.

Sensory evaluation

The initial plan of this study had included conducting a sensory evaluation and consumer acceptance tests. However, ethical approval was not obtained on time, therefore, it was not conducted.

Data analysis

A two-way analysis of variance (ANOVA) in SPSS Statistics version 26 was performed to determine if edible insects (mopane worm, *Gynanisa* caterpillar, and termite) influenced the nutrient composition of the porridge samples. The Turkey HSD test was used to separate the means, with the level of significance set at $p < 0.05$.

Results

Effect of insect meal on the colour of the porridges

Generally, the colour of the thin and crumbly porridges supplemented with edible insect meal appeared darker than that of the control (Table 3.1). The lightness of thin and crumbly porridges decreased with an increase in edible insect concentration. The lightness (L^*) of thin porridge supplemented with termites showed the greatest decrease in lightness from 0% (control), 5%, and 10% incorporation, ranging from 76.21, 65.16 to 56.81, respectively. The a^* (redness) was higher for termites at a 10% incorporation rate for both thin and crumbly porridges at 0.72 and

2.56, respectively. Hence, it shows the highest total colour change (ΔE) at 10% incorporation for both thin porridge and crumbly porridge at 21 and 20, respectively. The control was greener, with a^* value of -3.71 for thin porridge and -2.79 for crumbly porridge. Whereas the yellowing (b^*) increased with the incorporation of the edible insects, the highest b^* values reported were for the mopane-incorporated food products (thin and crumbly porridge) at 10% incorporation rate at 18.12 for thin porridge and 19.48 for crumbly porridge, the control presented the lowest b^* (yellowing) for both food products 6.00 for thin porridge and 11.67 for crumbly porridge.

Table 3.1: Effect of edible insects on the colour of food products (thin and crumbly porridges) supplemented with edible insects

Sample (thin porridge)	L*	a*	b*	ΔE
Control	76.21 ^a ±0.31	-3.71 ^a ±0.39	6.00 ^a ±0.78	-
Mopane 5%	70.2 ^c ±0.98	0.03 ^b ±0.42	11.02 ^d ±0.41	12.04
Mopane 10%	65.60 ^b ±0.77	-0.04 ^d ±0.53	18.12 ^e ±0.61	14.30
<i>Gynanisa</i> 5%	69.53 ^c ±0.17	-1.25 ^c ±0.22	14.96 ^c ±1.09	11.44
<i>Gynanisa</i> 10%	64.68 ^b ±1.11	-1.38 ^b ±0.40	12.76 ^b ±0.44	13.57
Termite 5%	65.16 ^b ±1.59	-2.04 ^d ±0.06	10.71 ^c ±0.61	12.16
Termite 10%	56.81 ^d ±0.16	0.72 ^e ±0.10	11.24 ^c ±0.17	20.58
Sample (crumbly porridge)	L*	a*	b*	ΔE
Control	72.61 ^a ±0.35	-2.79 ^a ±0.11	11.67 ^a ±1.43	-
Mopane 5%	67.20 ^b ±0.68	1.41 ^b ±0.09	19.48 ^b ±0.42	10.39
Mopane 10 %	55.31 ^c ±3.15	-0.19 ^c ±0.10	14.98 ^c ±0.56	17.80
<i>Gynanisa</i> 5%	67.59 ^b ±1.17	-0.42 ^d ±0.25	16.26 ^b ±1.16	7.20
<i>Gynanisa</i> 10%	62.20 ^d ±3.09	-0.19 ^b ±0.48	14.98 ^b ±1.56	13.51
Termite 5%	58.07 ^{cd} ±2.68	1.70 ^c ±0.33	15.14 ^b ±0.59	15.61
Termite 10%	53.47 ^d ±0.64	2.56 ^e ±0.19	13.86 ^b ±0.31	19.99

Values presented are means \pm standard deviations. L* stands for lightness coordinate from black (0) to white (100), a^* stands for red (+) to green (-) colour attribute, and b^* stands for yellow (+) to blue (-) colour attribute. ΔE is the total colour difference. Mean values with the same superscript in the same column are not significantly different ($p > 0.05$).

Proximate composition and gross energy

Table 3.2 shows the proximate composition of edible insects and maize meal samples (raw material). There were significant differences ($p < 0.05$) in the proximate composition of edible insects and maize meal samples used to make thin and crumbly porridges (Table 3.2). Overall, edible insect samples had the highest levels of protein, fats, and ash (total mineral) content compared with maize meal samples (Table 3.2). Termite samples had significantly higher protein content compared with the other insect types and maize meal. On the other hand, the *Gynanisa* caterpillar samples had higher total mineral (ash) content compared with other insect types and maize meal. The highest fat content was observed in mopane worm samples, hence having the highest gross energy (Table 3.2).

Table 3.2: Proximate composition (%) and gross energy (MJ/Kg) of edible insects and maize meal

	Protein	Fat	ADF	NDF	Ash	Moisture	Gross energy
Maize meal	8.25 ^a ±2.92	1.60 ^a ±0.43	0.60 ^a ±1.72	4.32 ^a ±2.76	0.91 ^a ±0.52	7.22 ^a ±6.09	18.24 ^a ±0.35
Termites	67.29 ^b ±1.20	7.71 ^c ±0.16	32.47 ^b ±0.98	55.78 ^b ±2.04	8.05 ^b ±0.07	4.80 ^b ±0.88	20.37 ^b ±2.02
<i>Gynanisa</i>	58.23 ^c ±0.81	14.21 ^b ±0.36	17.05 ^c ±1.81	38.11 ^c ±1.20	13.47 ^b ±0.15	7.60 ^a ±0.93	21.89 ^b ±0.46
Mopane	58.65 ^c ±0.41	16.93 ^b ±1.31	16.02 ^c ±1.58	35.83 ^c ±2.70	9.58 ^b ±0.55	7.87 ^a ±0.59	22.39 ^b ±2.03
p-values	0.001	0.001	0.001	0.001	0.001	0.628	0.001

Values presented are means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test ($p < 0.05$).

Figures 3.1a and 3.1b show the effect of edible insects on the proximate composition of thin and crumbly porridges supplemented with edible insect meal. There were significant differences in the proximate composition of crumbly and thin porridges supplemented with edible insect meal (Figures 3.1a and 3.1b). Overall, the protein, ash and fat content of crumbly and thin porridges increased with increasing insect concentration (Figures 3.1a and 3.1b). There was a significant increase in protein, fats, and ash (total mineral) content when 5% and 10% mopane worm, *Gynanisa* caterpillar, and termite meals were added to crumbly and thin porridges ($p < 0.05$) (Figures 3.1a and 3.1b). The highest protein content was observed in thin porridge supplemented with 10% termite meal. On the other hand, the highest ash was observed in thin porridge supplemented with 10% *Gynanisa* caterpillar meal. Conversely, the highest fat content was recorded in thin porridge samples supplemented with 10% mopane worm meal (Figure 3.1a). The highest protein content was observed in crumbly porridge supplemented

with 10% termite meal. On the other hand, the highest ash (total mineral content) was observed in crumbly porridge samples supplemented with 10% *Gynanisa* caterpillar meal. On the other hand, the highest fat content was recorded in crumbly porridge samples supplemented with 10% mopane worm meal (Figure 3.1b). Similarly, the highest gross energy was recorded in crumbly porridge samples supplemented with mopane worms at a 10% incorporation rate (Figure 3.1b).

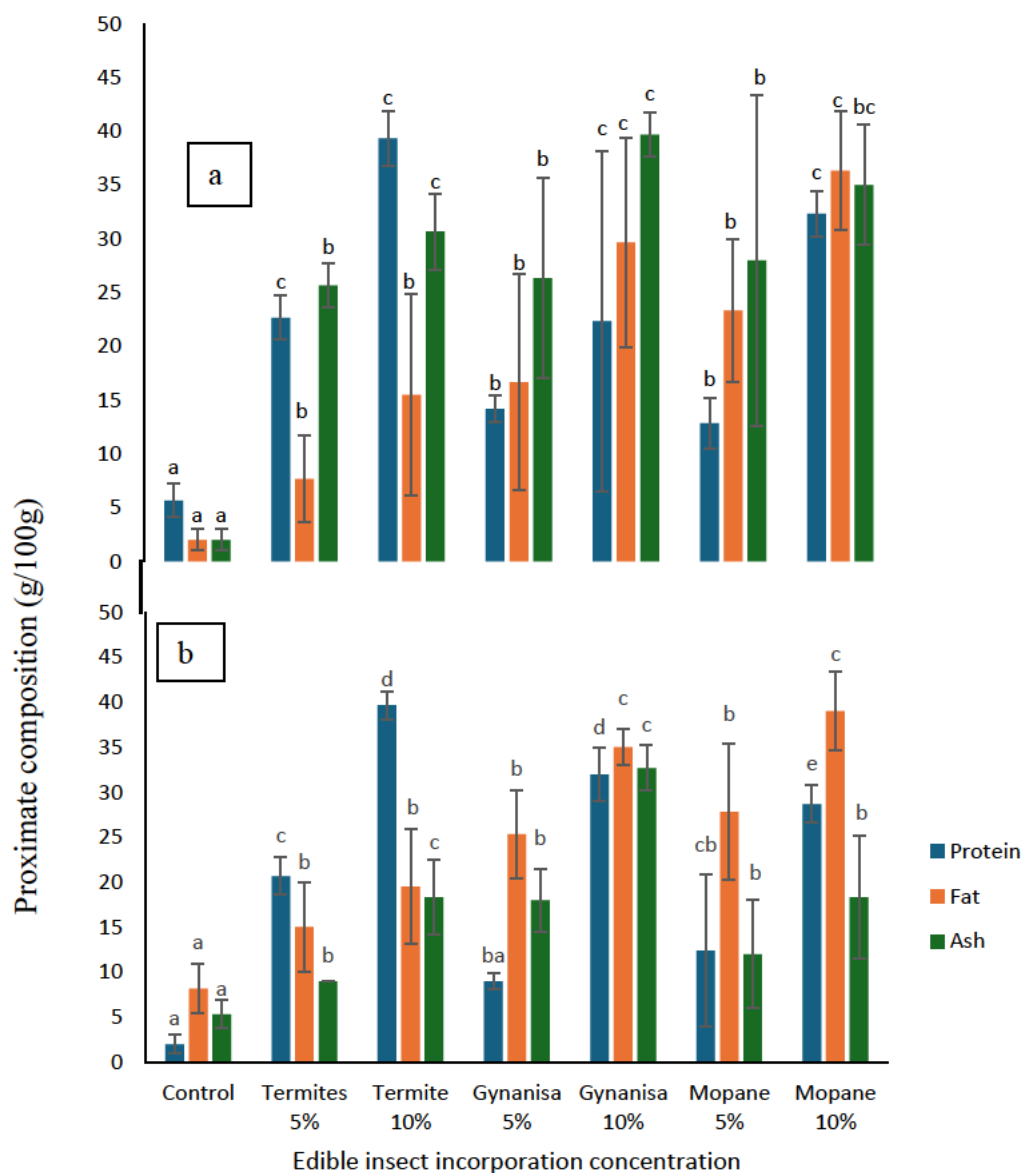


Figure 3.1: Effect of incorporating edible insects into thin (a) and crumbly (b) porridges on nutritional value (g/100g). Superscripts a,b,c and d show statistical differences; shared superscripts mean there is no statistical difference.

Amino acids

Edible insects had a significantly higher amino acid content compared to maize meal (Tables 3.3 and 3.4). Overall, edible insect samples had the highest levels of lysine and tryptophan content compared with maize meal samples (Table 3.3). Mopane worm samples had the highest tryptophan content compared with the other insect types and maize meal. The *Gynanisa* caterpillar sample had the highest lysine content compared with other insect types and maize meal samples. On the other hand, the termite samples had the lowest lysine content compared with other insect types, and the *Gynanisa* caterpillar sample had the lowest tryptophan content compared with other insect types.

Table 3.3: Effect of edible insects on essential amino acids composition (g/100g) of maize meal and edible insect meals

	Lysine	Tryptophan	Methionine	Valine	Leucine	Phenylalanine	Histidine	Threonine
Maize Meal	0.12 ^a ±0.02	0.19 ^a ±0.04	0.25 ^a ±0.03	0.28 ^a ±0.02	0.98 ^a ±0.07	0.36 ^a ±0.08	0.17 ^a ±0.02	0.19 ^a ±0.01
Mopane worm	3.52 ^b ±0.23	5.06 ^c ±0.83	1.12 ^{db} ±0.10	2.75 ^c ±0.19	3.44 ^{bc} ±0.19	2.62 ^{bc} ±0.29	1.67 ^b ±0.25	2.37 ^b ±0.30
Termites	3.14 ^b ±0.33	4.24 ^b ±0.38	0.72 ^{cb} ±0.27	3.45 ^b ±0.24	4.17 ^{bd} ±0.43	1.92 ^{bd} ±0.31	1.56 ^b ±0.22	2.52 ^b ±0.21
<i>Gynanisa</i> Caterpillar	3.58 ^b ±0.36	3.66 ^b ±0.32	0.99 ^b ±0.53	2.88 ^b ±0.07	3.61 ^b ±0.15	2.20 ^b ±0.11	1.52 ^b ±0.16	2.77 ^b ±0.28
p-value	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01

Values are presented as means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05).

Table 3.4: Effect of edible insects on non-essential amino acids composition (g/100g) of maize meal and edible insect meals

	Proline	Arginine	Serine	Glycine	Asparagine	Glutamine	Alanine
Maize meal	0.67 ^a ±0.06	0.18 ^a ±0.01	0.34 ^a ±0.03	0.22 ^a ±0.03	0.35 ^a ±0.01	1.24 ^a ±0.06	0.54 ^a ±0.05
Mopane worm	2.49 ^b ±0.26	3.13 ^b ±0.19	2.27 ^b ±0.10	2.42 ^b ±0.07	4.83 ^b ±0.21	6.63 ^b ±0.33	2.64 ^b ±0.17
Termites	4.05 ^c ±0.22	3.15 ^b ±0.38	2.19 ^b ±0.23	3.12 ^c ±0.29	4.37 ^b ±0.48	6.35 ^b ±0.61	6.44 ^c ±0.49
<i>Gynanisa</i> caterpillar	2.85 ^b ±0.24	3.49 ^b ±0.08	2.34 ^b ±0.25	2.64 ^b ±0.17	4.99 ^b ±0.44	7.03 ^b ±0.35	3.25 ^b ±0.21
p-values	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Values are presented as means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey

Figures 3.2a and 3.2b show the essential amino acid (lysine and tryptophan) content of thin and crumbly porridges supplemented with edible insects. There were significant differences in the essential amino acid content of thin and crumbly porridges supplemented with edible insects (Appendix 3.3). In general, the essential amino acid content of thin porridge increased with increasing concentration of edible insects except for leucine and tryptophan, which showed no significant differences in the thin porridge (Appendix 3.3 and Figure 3.2a). The highest histidine, threonine, and valine content were recorded in thin porridge supplemented with 10% termite meal (Appendix 3.3). On the other hand, the highest methionine and phenylalanine content were recorded in thin porridge supplemented with 5% mopane worm meal (Appendix 3.3). The highest lysine content was recorded in the thin porridge supplemented with 10% *Gynanisa* caterpillar meal (Figure 3.2a).

Similar trends were observed in the essential amino acid of crumbly porridge supplemented with edible insects (Appendix 3.3 and Figure 3.2b). Generally, the essential amino acid content of crumbly porridge increased with increasing concentrations of edible insects except for leucine and methionine, which showed no significant differences in the crumbly porridge supplemented with edible insects (Figure 3.2b). The highest histidine, threonine, and valine content were recorded in crumbly porridge supplemented with 10% termite meal. Similarly, the highest tryptophan and phenylalanine content were recorded in crumbly porridge supplemented with 10% mopane worm meal (Appendix 3.3 and Figure 3.2b). The highest lysine content was recorded in the crumbly porridge supplemented with 10% *Gynanisa* caterpillar meal (Figure 3.2b).

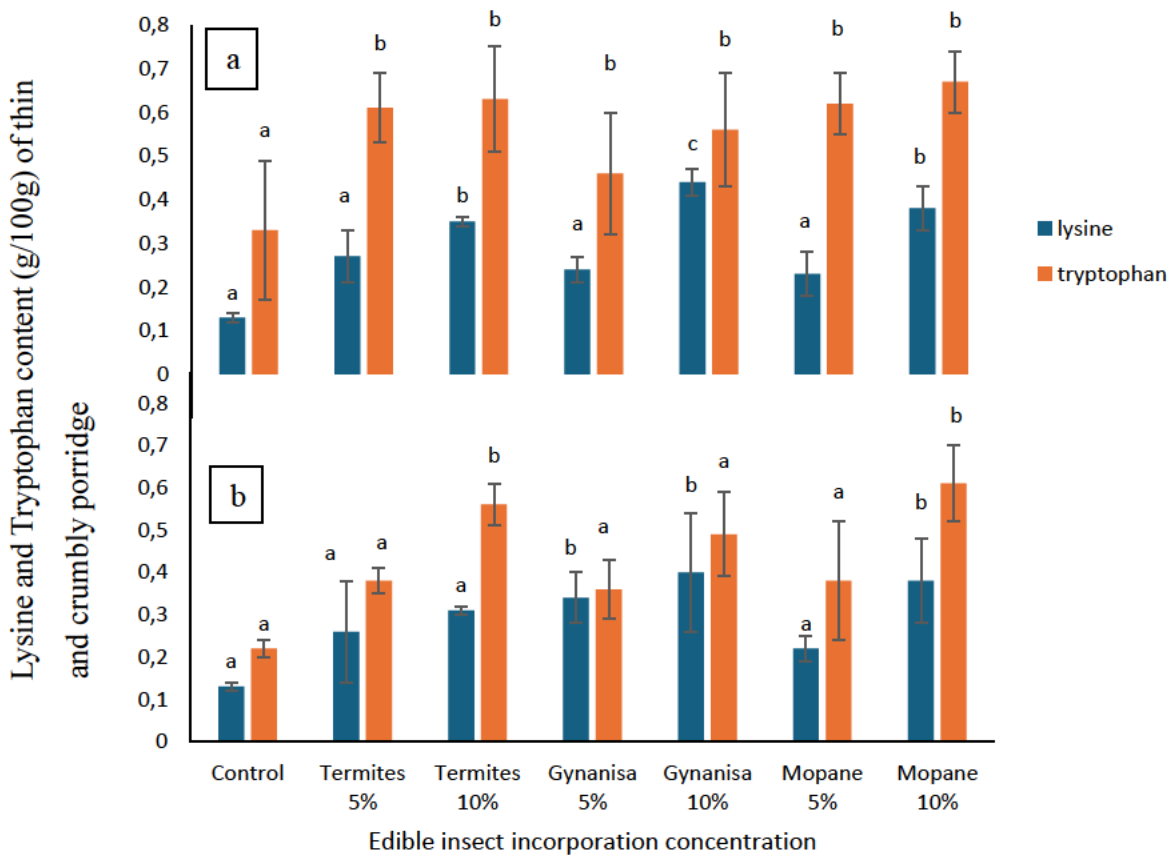


Figure 3.2: Effect of fortifying thin (a) and crumbly (b) porridge with edible insects on essential amino acids (g/100g) fortified with edible insects. Superscripts a and b show statistical differences; shared superscripts mean there is no statistical difference.

Mineral composition

There were significant differences ($p < 0.005$) in the mineral composition of edible insects and maize meal samples used to make thin and thick pap (Table 3.5). Overall, edible insect samples had the highest levels of zinc and iron content compared with maize meal samples (Table 3.5). Mopane worm samples had the highest zinc and iron content compared with the other insect types and maize meal. On the other hand, the termite samples had the lowest zinc and iron content compared with other insect types.

Table 3.5: Effect of edible insects on the mineral composition of maize meal and edible insects' meals

	Calcium	Copper	Iron	Potassium	Magnesium	Manganese	Sodium	Phosphorus	Zinc
	%	Mg/kg	Mg/kg	%	%	Mg/kg	%	%	Mg/kg
Maize Meal	2.67 ^a ±1.44	2.00 ^a ±1.00	2.67 ^a ±1.53	2.00 ^a ±0.87	2.00 ^a ±0.00	2.33 ^a ±1.44	2.00 ^a ±1.00	2.00 ^a ±0.87	3.00 ^a ±1.00
Termites	4.33 ^b ±2.08	6.17 ^b ±2.25	4.67 ^b ±2.52	6.33 ^b ±3.21	6.33 ^b ±2.84	6.17 ^b ±2.84	5.67 ^b ±2.08	5.33 ^b ±1.53	6.00 ^b ±1.00
Mopane worm	9.50 ^b ±2.29	8.50 ^b ±3.50	10.33 ^b ±2.08	8.67 ^b ±2.08	9.33 ^b ±2.25	8.50 ^b ±3.50	9.50 ^b ±2.29	9.00 ^b ±3.00	9.67 ^b ±1.53
<i>Gynanisa</i> caterpillar	9.50 ^b ±1.80	9.33 ^b ±2.08	8.33 ^b ±2.08	9.00 ^b ±3.00	8.33 ^b ±3.01	9.00 ^b ±2.65	8.83 ^b ±2.75	9.67 ^b ±1.53	7.33 ^b ±5.69
p-value	0.120	0.310	0.01	0.022	0.01	0.07	0.01	0.004	<0.01

Values are presented as means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05).

Figures 3.3a and 3.3b and Appendix 3.5 show the mineral element composition of thin and crumbly porridges supplemented with edible insect meal. The mineral element content of crumbly and thin porridges increased significantly with an increasing concentration of edible insects (Appendix 3.5). The highest zinc and iron content was recorded in the thin porridge supplemented with 10% mopane worm meal (Figure 3.3a). Similarly, the highest zinc content was recorded in crumbly porridges supplemented with 10% mopane worm meal (Figure 3.3b). Whereas the highest iron content was recorded in crumbly porridge supplemented with 10% *Gynanisa* caterpillar meal (Figure 3.3b).

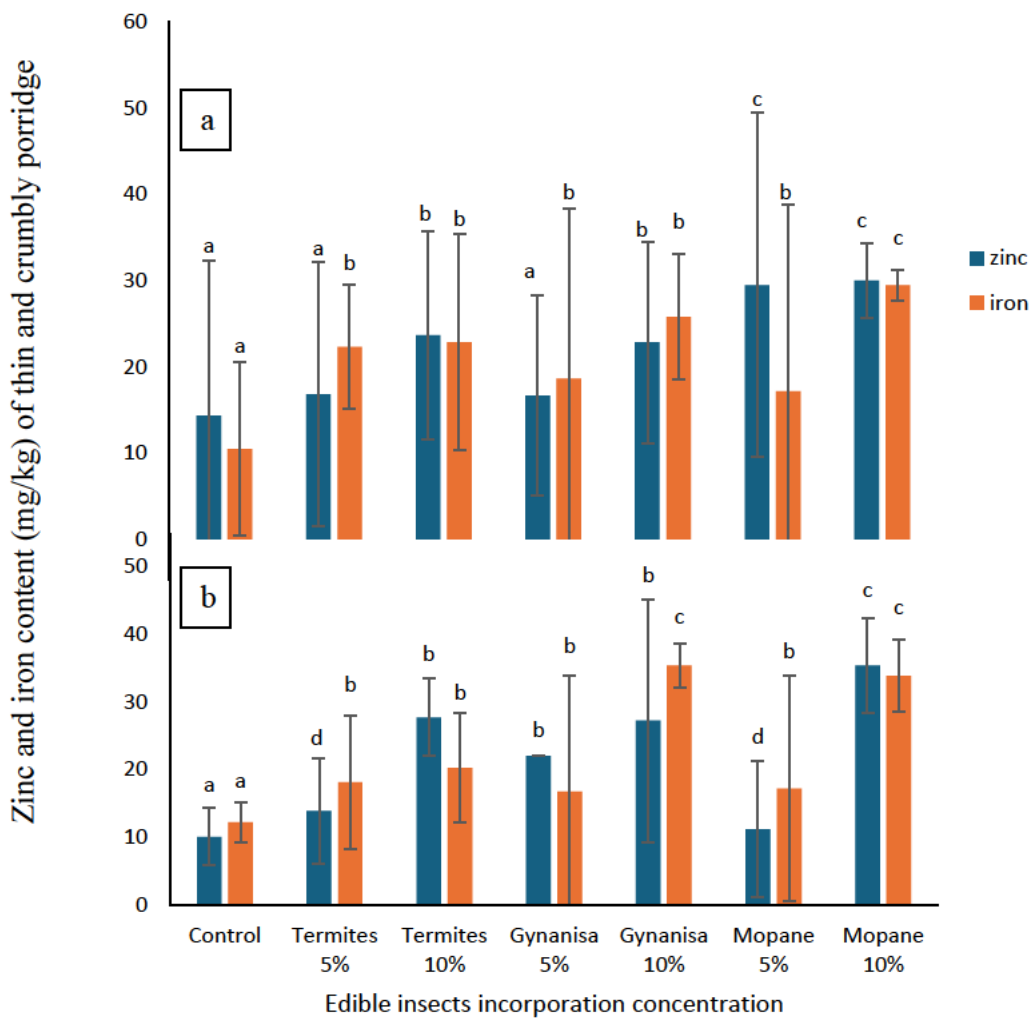


Figure 3.3: Effect of edible insects on zinc and iron (mg/kg) composition in thin (a) and crumbly (b) porridge fortified with edible insects. Superscripts a,b,c and d show statistical differences; shared superscripts mean there is no statistical difference.

Discussion

As the edible insect concentration increased, the lightness of thin and crumbly porridges significantly decreased, however, the highest darkening effect was observed in the thin and crumbly porridges supplemented with 5% and 10% termite meals. These results are consistent with a study conducted by Netshiheni et al. (2018), who found that the lightness of instant maize meal porridge decreased with the addition of termite meal and moringa leaf powder. The decrease in the lightness of the thin and crumbly porridge supplemented with termites might be attributed to the red pigment found in termites called prodigiosin (Netshiheni, 2023). The dark colour of thin and crumbly porridges supplemented with termites might negatively affect consumer acceptability of these porridges, as consumers are used to white maize meal food products (Huang and Lu, 2015; Maina, 2018; Pillay et al., 2020). For example, Pillay et al. (2011) reported a higher consumer acceptance of white maize porridge compared to yellow maize porridge in the Mkhambathini municipality, KwaZulu-Natal. However, other studies have shown that consumers are willing to try darker food products supplemented with edible insects when they are told about their nutritional value (Akande et al., 2020; Govender et al., 2020; Mafu et al., 2022). Therefore, educating consumers about the nutritional benefits of edible insects might play an important role in improving consumer acceptance of food products supplemented with edible insects.

Generally, the three insect types currently studied had appreciable amounts of protein, energy, fats, zinc, iron, and total minerals (ash) compared to the maize meal samples. This suggests that all three edible insects are suitable for improving the nutritional value of thin and crumbly maize meal porridges. However, the nutritional value varies with the insect type. Therefore, it is important to select edible insects with higher target nutrients such as protein, energy, zinc, iron, essential amino acids and minerals (ash) to improve the nutritional value of maize meal products, such as thin and crumbly porridges. The current study reported that termite samples, which had a greater protein content than mopane worms and *Gynanisa* caterpillar samples, would be the ideal insect type for boosting the protein content of thin and crumbly porridges. However, for nutritional intervention that requires increasing energy content, mopane worm samples will be most suitable because they contain appreciable protein content and higher fat and gross energy content. Protein-energy malnutrition is a serious health problem globally, but it is persistent in Sub-Saharan Africa and is caused by a lack of access to nutritious food and consuming starchy-based staples with a low intake of animal protein, dairy and fruits (Ndunge

Charles et al., 2024). Therefore, the incorporation of mopane worms into maize products would be important to address protein-energy malnutrition (PEM).

As stated above, maize products are a staple food in Southern Africa, especially in black communities, but they lack important nutrients such as protein (Tome and Bos, 2007). The protein content of thin and crumbly porridges increased with increasing concentrations of edible insects. Thin and crumbly porridges supplemented with 10% termite meals had the highest protein content. These results are consistent with other studies; for example, Adepoju and Ajayi (2021) reported that adding termites increased the protein content of maize meal pap used as complementary food for infants in Nigeria. Similarly, Anyiam et al. (2022) reported an increase in protein content in cassava mahewu supplemented with termite meal. Netshiheni et al. (2019) also reported an increase in the protein content of the maize meal instant porridge supplemented with termites and moringa leaf powder. These results suggest that termites are suitable for fortifying the protein of thin and crumbly porridges. However, as stated above, 5% and 10% termites resulted in the highest decrease in lightness of thin and crumbly porridge compared to the porridges supplemented with *Gynanisa* caterpillar and mopane worm. Although thin and crumbly porridges supplemented with 10% termites resulted in the highest protein content, their high darkening effect might affect consumer acceptance of thin and crumbly porridges. Studies have shown that consumers prefer lighter maize meal products, and the slightest colour change changes the way consumers perceive maize meal products (Pillay et al., 2020). For example, Netshiheni et al. (2019) reported a low acceptance of maize meal instant porridge supplemented with termites and moringa leaf powder compared to the control. Similarly, Hikeezi et al. (2012) reported that darker food products are poorly accepted because of learnt behaviour. Therefore, termites should be used to supplement already accepted darker porridges such as sorghum porridges, morvite, and maltabella porridges that are consumed in South Africa. However, for interventions to address protein deficiency, white maize meal food products should be fortified with 10% mopane worm and 10% *Gynanisa* caterpillar samples because they had the lowest darkening effect and had appreciable protein content. FAO does not have guidelines for the fortification of food with protein, its guidelines only focus on the fortification of food with micronutrients, therefore, there are no established FAO regulations or policy standards for fortifying food products with edible insects as a protein source. The result from the current study shows that supplementing maize meal food products with edible insects significantly increased their protein content, highlighting their potential use in fortifying

cereal grain staple foods. Therefore, the selection and use of edible insects in food fortification need to be included in the National Food and Nutrition Security Plan of South Africa.

The highest ash content was obtained in thin and crumbly porridges supplemented with 10% *Gynanisa* caterpillar samples. These results are similar to another study, which reported an increase in the ash content of cookies supplemented with sorghum and termites compared to the control (Awobusuyi et al., 2020). The increase in ash content of thin and crumbly porridge supplemented with edible insects indicates an increase in mineral composition. Therefore, the consumption of maize meal porridges supplemented with *Gynanisa* caterpillar meal may play a vital role in mitigating mineral deficiencies in South Africa and other parts of Africa that use maize meal as a primary food source.

Mineral deficiencies are prevalent in developing countries, but the most problematic are zinc and iron deficiencies (Godswill et al., 2020). Maize meal food products that are consumed in developing countries lack these minerals. Therefore, supplementing maize meal products (thin and crumbly porridge) with three insect types studied (mopane worm, termites, and *Gynanisa* caterpillar) significantly increased their mineral content. Higher zinc and iron content were observed in thin and crumbly porridges supplemented with 10% mopane worm samples. These results suggest that mopane worms would be more suitable for increasing the zinc and iron of cereal grain food products. Similarly, a study done in Zimbabwe reported an increase in zinc and iron in maize porridge supplemented with mopane worms (Ledbetter et al., 2024). In addition, Bauserman et al. (2015) reported that edible insects are a useful source of iron, and they reported a decrease in the effect of anaemia in children consuming complementary cereal fortified with caterpillars. Therefore, supplementing thin maize meal porridge with edible insects will help improve its mineral content. The consumption of thin porridge supplemented with edible insects can help mitigate the effect of mineral deficiencies among children in South Africa. According to the National Food and Nutrition Security Plan of South Africa, mandatory fortification programs of maize meal with vitamin A, thiamine, riboflavin, niacin, pyridoxine, folic acid, zinc, and iron were implemented in October 2003 (Steyn et al., 2008). However, fortification of maize meal and wheat flour has not been successful in addressing micronutrient deficiencies because commercially fortified foods are expensive and not accessible to the impoverished population living in rural areas (Van Jaarsveld et al., 2015; Siwela et al., 2020). In addition, the food fortification program did not include protein; however, protein deficiency remains a serious health problem in South Africa. (Yusufali et al., 2012). Currently, edible insects are not included in food fortification programs to mitigate the effects of different forms

of malnutrition in South Africa. Yet, the current study has shown that edible insects are good candidates to be used in fortifying cereal grain food products with protein and micronutrients. Therefore, policymakers need to select edible insect types that are rich in target nutrients and use them for interventions to reduce protein energy malnutrition and micronutrient deficiency.

The highest fat and energy content were reported in thin and crumbly porridges supplemented with 10% mopane worm. Similar results were obtained by Mashau et al. (2024), who reported a significant increase in the fat content of biscuits supplemented with mopane worm flour. Mopane worms derive their high fat content from the mopane tree that they mainly feed on, which contains high levels of lipids (Maleke et al., 2024). The high energy content in thin and crumbly porridge supplemented with mopane worms will mitigate the prevalence of energy deficiencies. Supplementing maize meal staple foods with mopane worms can play an important role in mitigating the effects of protein-energy malnutrition in developing countries (Rebe et al., 2024).

As previously discussed, maize products lack essential amino acids like lysine and tryptophan (Pillay et al., 2013). Lysine is an important molecule in the synthesis of proteins (Tome and Bos, 2007). On the other hand, tryptophan plays a vital role in the synthesis of nicotinamide hence, tryptophan is regarded as a dietary source of niacin (Fukuwatari and Shibata, 2013). The highest lysine content was recorded in thin and crumbly porridges supplemented with 10% *Gynanisa* caterpillar samples, while the highest tryptophan content was recorded in thin and crumbly porridges supplemented with 10% mopane worm samples. These findings are similar to the results reported by Ivanisova et al. (2023), who found an increase in the lysine content of crackers supplemented with cricket powder. Ogidi et al. (2023) also reported an increase in the lysine and tryptophan contents of wheat cookies supplemented with mushrooms, termites, and palm weevils. Lysine is a vital amino acid for bone growth, tissue repair, and collagen synthesis (Torricelli et al., 2002). Therefore, increased lysine content in thin and crumbly porridges will also promote healthy growth in younger children, hence mitigating the effects of stunted growth, which is mostly prevalent in resource-poor communities. Overall, the incorporation of edible insects into thin and crumbly porridge has significantly increased their nutritional value. Both food products (thin and crumbly porridge) retained high protein, zinc, and iron contents. Therefore, both porridges can play an important role in addressing protein, iron and zinc deficiencies that are prevalent in resource poor communities.

Conclusion

Mineral deficiency (zinc and iron) and protein-energy malnutrition are pressing health problems in Sub-Saharan Africa, and they are mainly caused by diets that are predominately made of starchy staples such as thin and crumbly maize meal porridges. Therefore, the fortifying of maize meal food products with edible insects could play a role in improving the protein, iron, zinc, energy, and amino acids of maize meal staple foods. The results from the current study indicated that the nutrient content varied with edible insect types; therefore, to improve the nutritional value of thin and crumbly maize meal porridges, it is important to select the insect type with higher target nutrients such as protein, iron, zinc, energy, and amino acid. To improve the protein, energy, zinc, and iron of thin and crumbly porridges, 10% mopane worms and *Gynanisa* caterpillar samples would be most suitable because they had higher ash, energy, zinc, iron, lysine, and tryptophan content, as well as an appreciable protein content. Although termites resulted in the highest increase in the protein content of thin and crumbly porridges, they also resulted in the highest decrease in lightness, resulting in the highest darkening effect of the two porridges compared to porridges supplemented with *Gynanisa* caterpillar and mopane worms. This might negatively affect consumer acceptability of maize meal food products, as consumers generally prefer lighter-coloured maize meal food products. Thin and crumbly porridges supplemented with mopane worms and *Gynanisa* caterpillar samples could significantly address protein energy malnutrition and micronutrient deficiencies, which remain a serious health concern in Africa. Further studies should investigate consumer acceptance and sensory evaluation and strategies to improve the physical characteristics of maize meal food products supplemented with edible insects.

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Chapter 4: CONCLUSION AND RECOMMENDATIONS

Introduction

Malnutrition, including protein-energy malnutrition and micronutrient deficiencies, constitutes a significant health concern globally, but they are prevalent in developing countries, including South Africa (Bain et al., 2013). In Africa, different forms of malnutrition are caused by poverty, which contributes to food insecurity and lack of access to nutritious food (Bain et al., 2013). As a result, resource-poor communities in Africa rely on starchy-based cereal grain staples such as crumbly and thin porridges (Ndunge Charles et al., 2024). These starchy cereal grain staples are rich in carbohydrates but low in protein, zinc, and iron, which contributes to protein energy malnutrition and micronutrient deficiencies (Ndunge Charles et al., 2024). Edible insects are rich in protein, zinc, iron, energy, vitamins, and some amino acids (Hlongwane et al., 2020). Therefore, fortifying cereal grain staple foods such as crumbly and thin porridges with edible insects can improve the nutrient value of staple cereal grain foods, which can play a role in addressing different forms of malnutrition (Tarahi et al., 2024). Several studies have explored fortifying food products like biscuits, bread, muffins, and pasta with edible insects (Awobusuyi et al., 2020; Zielinska et al., 2021). However, research on supplementing crumbly and thin porridge with mopane worms, termite workers, and *Gynanisa* caterpillars is limited. These edible insects are found abundantly in Southern Africa, and their consumption is declining. Therefore, supplementing common cereal grain food products (thin and crumbly porridges) with edible insects will promote their consumption and utilization. Thus, this study aimed to assess the effect of adding edible insects on the nutritional value and colour of thin and crumbly porridges

Key findings on the study objectives:

Objective 1: Review and analyse the existing literature on the nutritional value and consumer acceptance of food products supplemented with edible insects globally (Chapter 2).

The systematic review study on the nutritional value of food products supplemented with edible insects reported 26 edible insect species used to develop 12 food products. With over 2250 species (Omuse et al., 2024) of edible insects consumed as food globally, only 26 species have been used in food fortification. The selected insect species are edible insects with a history of being consumed in those countries, including termites in South Africa, Nigeria, and Kenya,

mealworms and crickets in European and American countries. The results showed that food products supplemented with edible insects had higher nutritional value, including proteins, zinc, and iron, when compared with the control.

Most studies reported high consumer acceptance of food products supplemented with edible insects, highlighting that the consumers were most willing to consume the food products after they were briefed about their nutritional value. In addition, the consumers were willing to try the food products supplemented with edible insects if the insects were not visible and the aroma was masked. Therefore, supplementing food products with edible insects masks the edible insects' component and helps promote the utilisation of edible insects. This strategy can be used in places/regions with a decline in entomophagy.

The current study revealed that more studies were conducted in developed countries and fewer in developing countries. This suggests that more studies should focus on edible insects and staple food products that are consumed in developing countries. Bakery products were the most used and selected food products in food fortification. Bakery products are well accepted worldwide and are a staple food in most parts of the world, particularly in developed countries. However, bakery products, such as bread, are not easily accessible or affordable in poor communities. In rural areas, people often must travel long distances to reach towns where bread is sold, and the bread available in local tuck shops is typically sold at inflated prices. As a result, the affordability of these food products becomes an issue as most families in rural areas consist of large families and are headed by elderly people and are mostly reliant on social grants as their primary source of income, hence they cannot afford to buy bread that will be enough for the whole family (Bavum et al., 2023). Therefore, more studies need to be done in Africa, focusing on fortifying Africa's staple food products with edible insects consumed and found in Africa. This will, therefore, provide a precise insight into how the fortification of common food products with edible insects would be received in Africa. Fortifying stable food products will ensure that the target population that is mostly affected by malnutrition gets the nutrients that are lacking in their diets.

Objective 2: To determine the effect of insect meal on the colour of thin and crumbly porridge supplemented with edible insects (Chapter 3).

Supplementing thin and crumbly porridges with edible insects decreased their lightness, causing them to appear darker (Chapter 3). The lightness of thin and crumbly porridges decreased with an increased concentration of edible insects. The change in colour of thin and

crumbly porridges after adding edible insects might negatively affect the consumer acceptance of these food products. Consumers are generally used to consuming maize meal food products that are lighter in colour (Pillay et al., 2011). Termites resulted in the highest darkening effect, followed by the mopane worm and the *Gynanisa* caterpillar resulted in the least darkening effect at both concentrations (5% and 10%). Therefore, the *Gynanisa* caterpillar would be the most suitable candidate to incorporate into white maize products when only considering the colour. However, studies investigating consumer acceptance and sensory evaluations of thin and crumbly porridges are required to determine how consumers will receive these food products.

Objective 3: To determine the effect of insect meal (mopane worm, termite (workers) and *Gynanisa* caterpillar) meal addition on proximate composition, mineral, and amino acid profile on thin and crumbly porridges (Chapter 3).

The results showed that mopane worm, termites, and *Gynanisa* caterpillar all had appreciable amounts of protein, energy, zinc, zinc, iron and some amino acids therefore the partial substitution of maize meal with the three edible insects resulted in a significant increase in protein, energy, zinc, iron and amino acids (lysine and tryptophan) of crumbly and thin porridges. Thin and crumbly porridges supplemented with 10% mopane worm, termite, and *Gynanisa* caterpillar had more than double the protein, zinc, iron, lysine, and tryptophan content compared to the control. Therefore, consumers of thin and crumbly porridge would get double the nutritional value they would normally get on thin and crumbly porridge not supplemented with edible insects, hence mitigating the effect of malnutrition.

The current study reported that supplementing thin and crumbly porridges with mopane worms, termites, and *Gynanisa* caterpillars resulted in a significant increase in mineral element content and the mineral element content of thin and crumbly porridges increased with increasing concentration of edible insects however the highest zinc and iron content was reported in 10% mopane worms. These results suggest that mopane worm samples will be the best candidate for the fortification of maize meal staple food with iron and zinc. Maize meal products (thin and crumbly porridges) are staple food sources in many poor communities where mineral deficiencies are prevalent (Rebe et al., 2024). Therefore, the increase in zinc and iron in thin and crumbly porridges supplemented with edible insects will reach most of the population where zinc and iron deficiencies are prevalent. This will thereby mitigate the prevalence of zinc and iron deficiencies. Duo et al. (2023) and Rafii et al. (2018) reported that maize products lack essential amino acids. Therefore, the increase in lysine and tryptophan content in thin and

crumbly porridges after adding different concentrations of insect meals is important as it will play a vital role in decreasing the cases of growth-related disorders, including stunted growth. Lysine plays an important role in the growth and health of bones (Aggarwal and Bains, 2022). The highest lysine content was reported in thin and crumbly porridges supplemented with 10% *Gynanisa* caterpillar, while the highest tryptophan was recorded in thin and crumbly porridges supplemented with 10% mopane worm. The fortification of maize meal with mopane worms and *Gynanisa* caterpillar will improve the protein, zinc, iron, lysine, and tryptophan content of maize meal products, such as thin and crumbly porridges, and their consumption will play an important role in reducing protein and energy malnutrition as well as mineral deficiencies in disadvantaged communities.

Recommendations

- Future research should investigate the allergens that are contained in edible insects that may cause allergic reactions in some individuals.
- Consumer perception and acceptance of thin and crumbly porridges supplemented with mopane worm, termites and *Gynanisa* caterpillar. This will give consumers perspective on incorporating edible insects into staple food, and this will aid the policymakers in including edible insects as a strategy to mitigate the effects of food and nutrition insecurity.
- Looking at the potential of insect farming is also crucial for sustainability. And the inclusion of edible insects in the policy document. Establishing edible insect farming will ensure sustainability and, hence, can be used as one of the strategies to ensure food sustainability.

Study strength

This study was comprehensive, utilising three different insect species and two types of maize meal porridges (thin and crumbly porridges). The analysis of nutritional composition offers valuable insights into the potential of edible insects as fortifying agents for maize-based food products, particularly in enhancing protein, micronutrients, and amino acid content. The key findings from the systematic review (chapter 2) revealed that the addition of edible insects into food products tripled the nutritional composition of the food products. This was further supported by the results of this study (chapter 3), which revealed that incorporating edible insects into maize porridges significantly improved their nutritional value, most notably in terms of protein, essential amino acids, iron, and zinc. These results highlight the promising

role of edible insects in boosting the nutritional profile of maize meal products. Furthermore, no previous research has explored the use of these three insect species (mopane worm, *Gyanisa* caterpillar and termites) to fortify crumbly porridge, a traditional staple food in KwaZulu-Natal (known as *uphuthu*) and the Eastern Cape (known as *umphokoqo*).

Study limitation

The limitation of this study was not getting the ethical clearance (despite addressing all the comments they had) to conduct the consumer acceptance and sensory evaluations of the thin and crumbly porridge supplemented with edible insects. As a result, that component was removed from this study. Sensory evaluation would have strengthened the findings of this study as it would have given the consumer perception and whether they would be willing to accept food products fortified with edible insects diets and further assess the quality of the two types of porridges (thin and crumbly porridges). The study is also limited by the use of only two maize porridges, one of which (crumbly porridge) is only popular in some parts of South Africa. In contrast, thin porridge is widely consumed across Africa. The inclusion of other maize products, such as pap (stiff porridge) which is commonly consumed across Africa could have broadened the study's relevance and appeal to a wider audience. The inclusion of visuals would have enhanced the readability and understanding of the colour changes of the food products.

Conclusion

Generally, supplementing maize meal with edible insects significantly increased the nutritional value of thin and crumbly porridges, particularly the protein, zinc, iron, energy, and essential amino acids (lysine and tryptophan). Overall, increasing the nutritional value of cereal grain stable food products will mitigate the effects of different forms of malnutrition, e.g., protein and energy malnutrition, as well as micronutrient deficiency (iron and zinc deficiencies), which are prevalent in sub-Saharan Africa. Edible insects can potentially improve the nutrient quality and quantity of cereal grain-stable food products. In addition, fortifying staple food products with edible insect meals can also play an important role in promoting consumer acceptability and the utilization of edible insects by reducing the fear, barriers, and stigma associated with consuming edible insects. Studies have shown that supplementing common food products with edible insects improves their sensory attributes and therefore increases their consumer acceptability. Overall, mopane worms and *Gyanisa* caterpillar would be the best candidates to fortify white maize meal products as they resulted in the least darkening effect and presented appreciable levels of protein, energy, fats, zinc, iron, lysine, and tryptophan.

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Appendices

Appendix 2.1: Nutrient composition (g/100g) of foods fortified with edible insects at different incorporation rates (%)

Edible insects	Food product	Nutrient	0%	5%	10%	15%	20%	Reference
Imbrasia oyemensis	Cookies	Protein	10.1±0.3	12.3±0.7	13.32±0.8	16.4±0.2	17.5±0.6	Aboubacar et al., 2022
		Fat	15.1±0.4	16.4±0.6	17.07±0.3	17.5±0.2	18.2±0.1	
		Carbohydrate	68.93±0.04	66.44±0.1	64.58±0.12	62.7±0.03	60.7±0.2	
		Fibre	0.1±0.06	1.05±0.02	1.1±0.01	1.14±0.08	1.2±0.05	
		Ash	0.57±0.10	0.76±0.03	1.1±0.05	1.4±0.05	1.66±0.8	
		Energy (kj)	453.4±1.20	464.3±0.7	466.6±0.3	473.5±0.6	476.6±1.1	
			0%	5%	10%	15%	20%	Reference
<i>Gonimbrasia zambesina</i>	Muffin	Protein	19.67±0.70	25.47±0.50	28.23±1.55	31.58±0.44	34.15±0.54	Ouma et al., 2022
		Fat	28.83±0.64	29.75±0.38	30.68±0.64	31.52±0.51	32.62±0.22	
		Carbohydrate	47.00±1.16	39.96±0.37	35.40±2.22	30.83±0.49	26.09±0.96	
		fibre	0.89±0.00	1.14±0.00	1.82±0.07	2.04±0.06	2.67±0.22	
		ash	0.93±0.09	1.11±0.11	1.18±0.01	0.23±0.26	1.35±0.20	
			0%	5%	10%	15%	References	
Termites	Biscuits	Protein	10.5 ± 0.4	36.4±0.4	38.3±0.5	41.0±0.40	Awobusuyi et al., 2020	
		Fat	14.3±0.4	22.3±0.5	25.2±0.4	28.2±0.4		
		Fibre	8.3±0.5	13.2±0.5	10.3±0.4	13±0.5		

		Ash	1.7±0.5	3.5±0.6	4.0±0.5	4.2±0.4	
			0%	5%	10%	15%	References
Cricket	Biscuits	Protein	9.48	11.22	12.97	14.71	Biro et al., 2020
		Fat	23.69	24.02	24.35	24.68	
		Carbohydrate	38.27	36.67	35.06	33.46	
		Fibre	7.00	6.66	6.32	5.98	
		Energy (kj)	410.68	413.50	416.32	419.14	

Appendix 2.1: Cont.

Edible insects	Food product		0%	5%	7%	10%	Reference
Grasshopper	Biscuits	Protein	10.61±0.18	14.28±0.28	15.36±0.51	16.45±0.84	Dewi et al., 2020
		Fat	19.98±0.45	19.68±1.57	21.97±1.56	22.25±0.49	
		Carbohydrate	60.09±0.54	56.95±1.33	54.71±1.20	52.12±0.73	
		Fibre	6.23	11.03	15.55	19.75	
		Ash	7.31	5.69	4.30	5.80	
		Energy (kj)	462.63±4.99	462.10±9.12	478.01±8.01	474±5.14	
	Food Product		0%	10%	15%	20%	Reference
Cricket	Biscuits	Protein	10.90±0.04	14.3±0.01	15.2±0.01	17.4±0.02	Duku et al., 2023
		Fat	17.3±0.04	17.8±0.03	21.00±0.02	22.7±0.02	
		Carbohydrate	66.6±0.04	61.9±0.04	59.0±0.01	52.3±0.03	
		Ash	1.1±0.01	1.45±0.03	1.47±0.05	2.00±0.02	
		Energy (kj)	3192±0.57	3262±0.47	3282±0.34	3335±0.29	
	Food Product		0%	10%	20%	30%	Reference
Bombay locust	Cake	Protein	14.94±0.58	18.40±0.59	20.83±0.15	24.94±0.30	Indrian et al., 2020
		Fat	21.55±0.57	22.17±0.36	21.49±0.41	21.90±0.64	
		Carbohydrate	21.08±1.84	19.42±1.36	19.10±0.89	14.26±0.48	
		Ash	1.26±0.08	1.29±0.06	1.33±0.04	1.35±0.02	

		Energy (kj)	339.94±3.62	350.83±6.32	353.13±6.06	354.33±5.86	
Food Product			0%	5%	7.5%	10%	Reference
Cricket	Cookies	Protein	3.9±0.45	8.9±0.27	11.9±0.32	13.3±0.29	Aleman et al., 2022
		Fat	33.8±1.34	31.5±1.05	30.2±1.34	28.5±1.07	
		Carbohydrate	48.1±1.33	44.4±1.89	41.3±1.33	39.8±1.89	
		Ash	2.9±0.03	2.8±0.02	2.6±0.03	2.5±0.02	

Appendix 2.1: Cont.

Edible insects	Food Product		0%	2%	5%	10%	Reference
Cricket	Muffin	Protein	11.84±0.24	12.27±0.18	14.58±0.54	16.51±0.23	Pauter et al., 2018
		Fat	23.46±0.74	23.64±0.08	24.39±0.17	25.34±0.75	
		Carbohydrate	44.29±0.18	41.82±0.49	38.17±0.09	34.45±0.37	
		Ash	1.00±0.14	1.10±0.14	1.33±0.32	1.65±0.21	
		Energy (kj)	435.66±8.28	429.12±1.91	430.51±0.27	431.90±4.35	
			0%	2%	6%	10%	Reference
Cricket	Muffin	Protein	7.8±0.55	7.63±0.53	9.07±0.64	10.45±0.73	Zielinska et al., 2021
		Fat	15.32±0.19	13.55±0.52	15.17±0.17	16.42±0.48	
		Carbohydrate	51.17±0.85	45.96±0.72	47.74±0.23	45.47±0.58	
		Ash	0.9±0.05	0.82±0.08	0.93±0.06	1.0±0.09	

		Energy (kj)	1568±8.0	1412±12.22	1527±15.56	1558±13.74	
Food product			0%	10%	20%	30%	Reference
Cricket	Pancakes	Protein	8.13±0.19	10.48±0.44	13.05±0.34	15.66±0.66	Mazurek et al., 2022
		Fat	7.93±0.1	8.50±0.19	9.54±0.29	10.46±0.18	
		Carbohydrate	34.23±0.88	29.64±0.55	24.69±0.88	19.94±0.26	
		Fibre	1.13±0.06	1.32±0.01	1.51±0.01	1.70±0.08	
		Ash	0.98±0.05	0.99±0.56	1.12±0.04	1.21±0.06	
		Energy (kj)	255.32±3.1	260.87±0.9	260.87±2.7	260.87±0.66	
Food product			0%	25%	50%	75%	Reference
Cricket	Porridge	Protein	17.58±0.23	19.18±0.28	21.04±0.19	22.87±0.45	Abonge et al., 2022
		Fat	9.87±0.75	11.04±0.70	14.02±0.35	15.61±0.3	
		Carbohydrate	56.69±0.55	52.77±0.02	45.73±0.55	41.49±0.51	
		Fibre	4.63±0.18	5.41±0.56	7.45±0.28	9.06±0.12	
		Ash	1.78±0.32	1.67±0.16	2.13±3.90	1.72±0.45	

Appendix 2.1: Cont.

Edible insects	Food product		0%	2%	6%	10%	Reference
		Protein	7.8±0.55	7.9±0.55	9.16±0.64	8.63±0.6	
		Fat	15.32±0.19	14.14±0.38	16.68±0.13	16.39±0.1	
Mealworm	Muffins	Carbohydrate	51.17±0.85	47.75±0.67	47.43±0.55	44.0±0.42	Zielinski et al., 2021
		Ash	0.9±0.05	0.88±0.07	0.95±0.05	0.98±0.05	
		Energy (kj)	1569±8.0	1469±11.2	1527±15.56	1558±13.74	
	Food product		0%	10%	20%	30%	Reference
		Protein	8.13±0.19	9.29±0.54	10.53±0.68	11.73±0.38	
		Fat	7.93±0.1	8.70±0.37	9.96±0.45	11.10±0.1	
Mealworm	Pancake	Carbohydrate	34.23±0.88	29.73±0.43	25.05±0.33	20.55±0.77	Mazurek et al., 2022
		Fibre	1.13±0.06	1.22±0.05	1.27±0.05	1.33±0.04	
		Ash	0.98±0.05	0.91±0.02	0.87±0.04	0.86±0.04	
		Energy (kj)	255.32±3.1	263.74±2.4	269.66±2.3	275.86±2.6	
	Food product		0%	10%	20%	30%	Reference
		Protein	9.4±0.01	11.07±0.08	13.01±0.06	14.92±0.05	

		Fat	21.98±0.29	22.09±0.75	24.68±0.09	25.80±0.45	
Darkling beetle	Cookies	Carbohydrate	64.94±0.28	63.99±0.53	57.73±0.22	53.84±0.44	Sriprablom et al., 2022
		Ash	1.49±0.01	1.68±0.02	1.74±0.04	1.83±0.02	
		Energy (kj)	495.21±1.4	499.05±0.52	505.08±0.33	505.92±2.53	
	Food product		0%	10%	20%	30%	Reference
		Protein	9.4±0.01	11.08±0.06	12.80±0.03	14.73±0.02	
		Fat	21.98±0.29	23.57±0.20	25.45±0.36	26.33±0.44	
Mealworm beetle	Cookies	Carbohydrate	64.94±0.28	60.54±0.40	56.16±0.51	52.91±0.49	Sriprablom et al., 2022
		Ash	1.49±0.01	1.59±0.02	1.74±0.01	1.84±0.01	
		Energy (kj)	495.21±1.4	498.60±0.43	504.88±1.25	507.45±1.99	
	Food Product		0%	13%	17%	20%	Reference
		Protein	7.8±0.2	16.11±0.09	19.00±0.07	21.82±0.51	
mealworm	Biscuits	Fat	20.8±0.3	13.06±0.06	15.32±0.07	16.59±0.12	Ortola et al., 2023
Edible insects	Food Product		0%	15%	20%	30%	Reference
		Protein	9.09±0.46	10.82±0.5	11.97±0.5	13.52±0.6	

		Fat	27.03±1.48	28.47±0.36	26.97±1.69	27.17±0.39	
Mealworm	Biscuits	Carbohydrate	63.6±1.63	60.27±1.72	60.36±1.49	58.69±1.63	Zielinska and Pankiewicz, 2020
	Food products		0%	5%	10%	15%	Reference
		Protein	11.30±0.12	14.13±0.11	16.95±0.16	19.77±0.04	
		Fat	2.23±0.04	3.07±0.01	3.92±0.02	4.77±0.06	
Mealworm	Bread	Carbohydrate	62.09±0.45	59.10±1.89	56.10±0.49	53.11±1.05	Gantner et al., 2022
		Fibre	7.47±0.87	7.56±0.45	7.65±0.61	7.74±0.82	
	Food Product		0%	5%	10%	15%	Reference
Mealworm	Bread	Protein	9.63±0.01	12.63±0.16	13.21±0.21	13.73±0.04	Khuenpet et al., 2020
	Food product		0%	5%	10%	15%	Reference
Termites	Bread	Protein	10.60±0.90	15.63±1.24			Kinyuru et al., 2009
	Food Product		0%	2%	6%	10%	Reference
Buffalo worm	Snacks	Fat	3.4±0.4	3.3±0.9	2.6±0.5	2.2±0.5	Kowalski et al., 2022
		Ash	1.49±0.01	1.56±0.01	1.73±0.01		
	Food Product		0%	2.5%	5%	7.5%	Reference

		Protein	14.46±0.04	14.81±0.08	16.87±0.13	17.87±0.13	Cvalho et al., 2023
Cricket	Meat	Fat	20.73±0.48	20.32±0.41	20.55±0.23	21.69±0.08	
		Ash	2.38±0.01	2.28±0.03	2.41±0.02	2.50±0.02	
		Food product	0%	8%	16%	24%	Reference
Cricket	Snacks	Protein	0.45±0.05	5.55±0.07	10.70±0.14	15.85±0.21	Akullo et al., 2016
		Food product	0	2	6	10	Reference
Cricket	Snacks	Ash	1.80±0.03	1.95±0.04	2.02±0.06	2.17±0.04	Kryzstof et al., 2019

Appendix 2.1: Cont.

Edible insects	Food Product		0%	10%	30%	Reference
Cricket	Bread	Protein	14.69±0.19	26.89±0.76	27.72±0.59	Osimanu et al., 2018
		Fat	0.10±0.01	1.53±0.04	6.38±0.28	
		Fibre	0.45±0.01	2.44±0.11	2.58±0.05	
		Ash	0.69±0.01	1.52±0.01	1.57±0.01	
		Energy (kj)	259.50±0.97	281.57±8.08	262.99±11.01	
	Food Product		0%	15%	30%	Reference
Mealworm	Snacks	Protein	10.78±0.02	13.48±0.04	15.51±0.04	Kowalski et al., 2022
		Fat	36.20±0.06	32.91±0.08	26.69±0.11	
	Food Product		0%	35%	70%	Reference
Palm weevil	Biscuits	Protein	8.01±0.05	9.63±0.08	11.68±0.42	Ayensu et al., 2019
		Fat	23±0.5	34±2.44	33±2.08	
		Carbohydrate	57.49±1.29	43.07±2.6	32.88±1.86	
		Fibre	3±0.4	4±0.00	5±1.0	
		Ash	1.61±0.01	1.64±0.01	2.10±0.01	
		Energy (kj)	468.97±0.65	516±7.38	577.12±15.15	
	Food Product		0%	10%	20%	Reference

Mealworm	Cake	Protein	5.08±0.03	6.32±0.03	8.04±0.03	Kowalski et al., 2022
		Fat	0.58±0.03	1.93±0.01	3.50±0.06	
		Ash	0.22±0.01	0.3±0.01	0.46±0.00	
Food Product			0%	10%		Reference
Cricket	Biscuits	Protein	9	12		Homann et al., 2017
		Fat	37	38		
		Carbohydrate	51	53		
		Fibre	1.7	2.4		
		Ash	1.9	2.2		
		Energy (kj)	1.94	1.94		

Appendix 2.1: Cont.

Edible insect	Food product		0%	10%	20%	Reference
Mealworm	Snacks	Protein	11.7	15.9	20.4	Severini et al., 2018
		Ash	0.7	1.0	1.3	
Food Product			0%	10%	30%	Reference
Mealworm	Snacks	Protein	12.53±1.06	15.59±0.13	24.98±3.27	Roncolini et al., 2020
		Fat	0.13±0.01	0.48±0.10	5.34±0.01	
		Fibre	3.27±0.10	4.38±0.50	6.36±1.19	

		Ash	0.55±0.04	0.77±0.02	1.37±0.07	
		Energy (kj)	327.61±12.44	330.26±3.75	351.51±10.43	
	Food Product		0%	15%	30%	Reference
Grasshopper	Snacks	Protein	10.78±0.02	13.11±0.12	13.69±0.16	Jimenez et al., 2020
		Fat	36.20±0.06	35.48±0.23	29.35±0.23	
	Food Product		0%	15%	30%	Reference
Grasshopper	Snacks	Protein	10.78±0.02	13.11±0.12	13.69±0.16	Jimenez et al., 2020
		Fat	36.20±0.06	35.48±0.23	29.35±0.23	
	Food product		0%	15%	30%	Reference
Mealworm	Bread	Protein	10.78±0.02	13.23±0.15	14.06±0.01	Kowalski et al., 2022
		Fat	36.20±0.06	34.07±0.01	32.62±0.16	
		Ash	1.49±0.01	1.52±0.01	1.57±0.00	
	Food product		0%	10%	20%	Reference
Grasshopper	Bread	Protein	112±11	148±4	174±6	Haber et al., 2019
		Fat	10 ±1	18±1	30±1	
		Fibre	12±3	13±3	16±1	
		Ash	19±0.1	24±0.1	26±0.1	

Appendix 2.1: Cont.

Edible insects	Food Product		0%	10%	Reference
Cricket	Cookies	Protein	8.47±0.01	11.70±0.00	Ogidi et al., 2023
		Fat	14.04±0.61	13.20±0.65	
		Carbohydrate	57.16±1.20	53.80±2.10	
		Fibre	9.63±0.10	11.31±0.40	
		Ash	2.30±0.00	3.60±0.30	
	Food Product		0%	5%	Reference
Mealworm	Bread	Protein	12.69±0.60	45.09±0.82	Gonzalez et al., 2019
		Fat	1.19±0.02	35.82±0.66	
		Carbohydrate	85.57±0.58	14.84±0.35	
		Ash	0.64±0.01	4.25±0.00	
	Food Product		0%	15%	Reference
Mealworm	Muffins	Protein	5.85±0.82	11.70±0.81	Cabuk et al., 2021
		Fat	31.21±1.66	36.56±1.26	
		Carbohydrate	34.56±4.02	22.07±1.63	
		Energy (kj)	442.54±2.62	464.09±11.28	
	Food Product		0%	10%	Reference

Cricket	Bread	Protein	16.91±0.55	21.13±0.25	Bawa et al., 2020
		Fat	11.99±1.11	14.49±0.28	
		Carbohydrate	68.86±0.54	61.63±0.48	
		Fibre	0.14±0.03	0.77±0.07	
		Ash	2.25±0.02	2.76±0.01	
Food Product			0%	10%	Reference
Cricket	Cookies	Protein	9.45±0.73	15.79±0.09	Bawa et al., 2020
		Fat	24.66±2.97	23.31±0.79	
		Carbohydrate	64.49±1.84	59.79±0.84	
		Fibre	0.10±0.00	0.64±0.07	
		Ash	1.41±0.41	1.09±0.06	

Appendix 2.1: Cont.

Edible insects	Food Product		0%	5%	Reference
Black soldier fly	Bread	Protein	12.69±0.60	48.82±0.76	Gonzalez et al., 2021
		Fat	1.19±0.02	30.69±0.80	
		Carbohydrate	85.57±0.58	16.24±0.63	

		Ash	0.64±0.01	4.25±0.01	
	Food Product		0%	5%	Reference
Cricket	Porridge	Protein	4.28	5.98	Kinyuru et al., 2021
		Fat	8.75	9.21	
		Carbohydrate	43.18	40.75	
		Fibre	3.24	3.34	
		Energy (kj)	251.07	251.41	
	Food Product		0%	15%	Reference
Grasshopper	Muffin	Protein	5.85±0.82	12.91±	Cabuk et al., 2021
		Fat	31.21±1.66	36.47±0.75	
		Carbohydrate	34.56±4.02	21.87±0.58	
		Energy (kj)	442.54±2.62	467.37±6.52	
	Food product				Reference
Palm weevil	Cookies	Protein	8.47±0.01	12.00±0.80	Ogidi et al., 2023
		Fat	14.04±0.61	13.10±0.00	
		Carbohydrate	57.16±1.20	53.60±0.85	
		Fibre	9.63±0.10	11.31±0.04	
		Ash	2.30±0.00	3.50±0.11	

Food Product		0%	5%	Reference
Cricket	Protein	12.69±0.60	56.58±0.86	Gonzalez et al., 2020
	Fat	1.19±0.02	27.08±0.72	
	Carbohydrate	85.57±0.58	12.33±0.41	
	Ash	0.64±0.01	4.02±0.01	

Appendix 2.1: Cont.

Edible insects	Food product	0%	5%	10%	15%	20%	25%	Reference	
Cricket	Biscuits	Protein	09.64±0.2 1	11.61±0.5 6	13.43±0.38	16.45± 0.34	19.90±0.44	21.66±0.40	Koffi et al., 2013
		Fat	21.51± 0.43	20.26 ±0.87	0.08±0.66	19.99 ± 0.75	19.59±0.84	19.03±0.92	
Food Product		0%	10%	15%	20%	25%	30%	Reference	
	Protein	15.75±3.5 7	18.97±0.3 7	21.90±0.46	22.79±0.0 7	25.86±0.95	28.46±0.01		

Cricket	Bread	Carbohydrate	73.53±0.0 7	68.03±0.7 6	65.55±0.72	63.01±1.7 9	58.04±0.34	56.65±1.39	Mafu et al.,2022
	Food product		0%	3%	5%	7%	10%		Reference
		Protein	10.35±0.1	15.37±0.2 7	13.34±0.10	12.79±0.1 0	12.25±0.17		
Grasshopper	Sausages	Fat	13.94±0.3	14.27±0.1 3	13.36±0.25	13.68±0.0 2	13.01±0.07		Lopes, 2022
		Ash	2.53±0.10	3.41±0.02	3.05±0.02	3.19±0.04	3.21±0.01		
	Food product		0%	5%	10%	15%			Reference
Termites	Bread	Protein	10.60 ±0.90	15.63±1.2 4					Kinyuru et al., 2009
	Food product		0%	2%	6%	10%			Reference
Cricket	Snacks	Fat	3.4±0.4	3.3±0.9	2.6±0.5	2.2±0.5			Kowalski et al., 2022
		Ash	1.49±0.01	1.56±0.01	1.73±0.01				
	Food product		0%	2.5%	5%	7.5%			Reference

		Protein	14.46±0.0	14.81±0.0	16.87±0.13	17.87±0.1	
				8		3	
Cricket	Meat	Fat	20.73±0.4	20.32±0.4	20.55±0.23	21.69±0.0	Cvalho et al., 2023
				1		8	
		Ash	2.38±0.01	2.28±0.03	2.41±0.02	2.50±0.02	
	Food product		0%	8%	16%	24%	Reference
Termites	Snacks	Protein	0.45±0.05	5.55±0.07	10.70±0.14	15.85±0.2	Akullo et al., 2016
						1	

Note: Values are mean ± Standard deviation of food products fortified with edible insects, % (percentages) on the top are incorporation rates.

Appendix 2.2: Comparison of mineral content of food enriched with edible insects at different incorporation rates (%)

Edible insects	Food product	Nutrients	0%	5%	10%	15%	Reference
Termites	Biscuits	Iron	2.5±0.6	28.5±0.4	34.2±0.5	37.4±0.4	Awobusuyi et al., 2020
		Zinc (mg)	2.5±0.5	8.4±0.6	10.4±0.4	14.8±0.4	
		Phosphorus (mg)	0.8±0.5	22.5±0.5	31.2±0.4	37.6±0.5	
		Potassium (mg)	1.8±0.6	12.5±0.4	18.6±0.5	22.9±0.4	
	Food product		0%	5%	7%	10%	Reference
Grasshopper	Biscuits	Iron	0.28±0.01	0.40±0.06	0.36±0.03	0.41±0.11	Dewi et al., 2020
		Zinc (mg)	0.075	0.0810	0.084	0.109	
	Food product		0%	10%	15%	20%	Reference
Cricket	Biscuits	Iron	23.3	30.5	37.2	52.1	Duku et al., 2023
		Zinc (mg)	29.45	34	28.9	37.9	
	Food product		0%	2.5%	5%	7.5%	Reference
Cricket	Meat	Iron	0.81±0.16	0.82±0.06	0.94±0.02	1.05±0.01	Cavalheiro et al., 2023
		Zinc (mg)	1.22±0.05	1.74±0.03	2.37±0.01	2.66±0.05	

		Potassium (mg)	261.80±3.7 7	258.14±2.8 1	295.67±1.7 4	298.51±15.8 5			
	Food product		0%	5%	10%	15%	20%	Reference	
<i>Gonimbrasia zambesina</i>	Muffin	Iron	4.49±0.19	4.67±0.31	4.79±0.04	4.91±0.04	4.98±0.27	Ouma et al., 2022	
		Zinc (mg)	2.31±0.01	2.90±0.06	3.37±0.40	3.37±0.40	3.40±0.14		
		Phosphorus (mg)	172.93±3.0 0	174.7±1.06	177.91±3.8 0	182.28±4.51	194.19±12		
		Potassium (mg)	156.10±2.4 0	161.59±5.1 6	197.36±4.3 5	242.11±4.32	273.4±9.25		
	Food product		0%	5%	10%	15%	20%	25%	Reference
Cricket	Biscuits	Iron	13.52±0.96	18.27±0.85	26.19±0.27	31.55±0.45	36.85±0.67	43.33±0.93	Koffi et al., 2013
		Zinc (mg)	3.62±0.12	5.41±0.24	7.36±0.36	7.67±0.48	8.6±0.51	12.85±0.74	
		Phosphorus (mg)	250.55±3.2 1	275.42±2.6 6	298.52±2.5 2	365.13±2.89	437.55±2.4	454.68±3.4 5	
		Potassium (mg)	271.17±2.3 6	340.33±1.2 5	381.08±3.2 1	407.33±2.45	453.61±2.7	478.33±3.1 2	

Appendix 2.2: Cont.

Edible insects	Food Product		40%		References
	Biscuit	Zinc (mg)	9.31±0.02		Akande et al., 2020
		Phosphorus (mg)	87.20±0.03		
		Potassium (mg)	121.80±0.17		
			40%		Reference
Locust	Biscuits	Zinc (mg)	11.37±0.06		Akande et al., 2020
		Phosphorus (mg)	127.70±0.03		
		Potassium (mg)	168.22±0.04		
	Food product				Reference
Cricket	Porridge	Iron	9.86±2.08	8.56±1.45	Maiyo et al., 2022
		Zinc (mg)	1.86±0.04	3.23±0.28	
		Phosphorus (mg)	221.63±5.57	372.71±19.14	
	Food product				Reference
		Iron	9.86±2.08	19.48±6.69	Maiyo et al., 2022
	Porridge	Zinc (mg)	1.86±0.04	3.71±0.18	
		Phosphorus (mg)	221.63±5.57	469.28±9.55	
	Food product				Reference
	Porridge	Iron	9.86±2.08	9.18±1.18	Maiyo et al., 2022

		Zinc (mg)	1.86±0.04	3.39±0.31	
		Phosphorus (mg)	221.63±5.57	458.70±3.76	
	Food product		0%	10%	Reference
	Snacks	Iron	32.5	135.0	Roncolini et al., 2020
		Zinc (mg)	103.9	363.6	
		Phosphorus (mg)	36.7	143.3	
	Food product				Reference
		Iron	378.04±11.45	818.00±30.05	
Cricket	Cookies	Zinc (mg)	412.02±8.03	601.04±18.18	Ogidi et al., 2023
		Potassium (mg)	448.76±32.11	573.81±43.80	

Appendix 2.2: Cont.

Edible insects	Food product		0%	10%	Reference
Cricket	Cookies	Iron	0.87±0.32	1.37±0.13	Bawa et al., 2020
		Phosphorus (mg)	82.1±1.72	143.14±2.39	
	Food product		0%	10%	Reference
Cricket	Bread	Iron	1.55±0.02	3.28±1.47	Bewa et al., 2020
		Phosphorus (mg)	156.72±1.16	221.66±2.15	
	Food product				Reference
Cricket	Cookies	Iron	109.63±7.00	426.19±22.80	Ogidi et al., 2023
		Zinc (mg)	205.00±9.04	345.80±10.82	
		Potassium (mg)	217.44±0.04	317.50±18.03	
	Food product				Reference
Palm weevil	Cookies	Iron	109.63±7.00	537.90±30.95	Ogidi et al., 2023
		Zinc (mg)	205.00±9.04	321.77±14.88	
		Potassium (mg)	217.44±0.04	304.11±21.80	
	Food product				Reference
	Cookies	Iron	109.63±7.00	507.71±8.04	Ogidi et al., 2023
		Zinc (mg)	205.00±9.04	335.00±9.0	

		Potassium (mg)	217.44±0.04	311.32±8.91	
	Food product		0%	10%	Reference
	Biscuit	Iron	1.0	1.6	Homann et al., 2017
		Zinc (mg)	1.1	3.1	
	Food product		0%	5%	Reference
Termite	Bread	Iron	1.20±0.10	1.80±0.22	Kinyuru et al., 2009
		Zinc (mg)	2.78±0.60	3.23±0.29	
	Food product		0%	5%	Reference
Cricket	Bread	Iron	5.04	5.64	Kinyuru et al., 2021

Appendix 2.3: Consumer acceptance of food products enriched with edible insects

Reference	Product	Insect Used	Consumer Acceptance	Key Comments
Abonge et al., 2022	Complementary Porridge	Cricket Flour	Moderate acceptance.	Enhancing the taste was recommended but it was accepted by the caregivers as a suitable complementary food
Adamek et al., 2018	Energy and Protein Bars	Cricket flour	High acceptance.	It was not visually appealing however the benefits Appearance was initially a concern but improved with flavour variety and labelling as "energy-boosting."
Adeboye et al., 2016	Cookies	Palm Weevil Larvae Flour	Moderate acceptance.	Scepticism was initially noted; however, that changed with knowing that it is a good protein source and increased acceptance when labelled as a protein source.
Akande et al., 2020	Biscuits	Silkworm Pupae, Locusts	Moderate acceptance.	Knowledge about nutritional value improved acceptance, particularly with young adults who were more open to trying the product.
Anyesu et al., 2019	Biscuits	Palm Weevil Larvae	High acceptance.	Masking the insect flavour played a vital role in enhancing acceptability.
Bawa et al., 2020	Bread and Cookies	House Cricket	High acceptance.	Consumers were concerned about the visibility of the edible insects in bread
Duku et al., 2023	Biscuits	Sorghum and Cricket Powder	High acceptance.	Changes in the colour profile raised concerns and scepticism about trying the biscuits
Gantner et al., 2022	Wheat Bread	Mealworm meal	Moderate acceptance.	Masking the insects' flavour was recommended, and improved acceptability with nutrient information

Homann et al., 2017	Biscuits	Cricket (Acheta domesticus)	High acceptance.	Younger children showed more willingness to try the food product, and they were more accepting of a decreased visibility of the edible insects.
Mafu et al., 2022	Whole Wheat Bread	Cricket meal	High acceptance.	Knowledge about nutritional value plays an important role in the acceptance of the food product.
Roncolini et al., 2020	Pork Pate	Cricket meal	High acceptance.	Consumer education about the nutritional value of edible insects is recommended to improve acceptance.
Mazurek et al., 2022	Pancakes	mealworm, buffalo worm and cricket flour	Moderate acceptance.	Masking the flavour of edible insects improved acceptance; improved acceptance in taste tests with additional sweeteners.



Appendix 3.1: Dried edible insects A-termites, B-*Gynanisa* caterpillar, C-mopane worm

Appendix 3.2: Effect of edible insects on nutritional value (g/100g) and gross energy (MJ/Kg) in uphuthu fortified with edible insects at different incorporation rates

Crumbly porridge	Protein	Fat	ADF	NDF	Ash	Moisture	Energy
Control	2.00 ^a ±1.00	8.17 ^a ±2.75	7.33 ^a ±6.81	9.67 ^a ±8.02	5.33 ^a ±1.53	14.00 ^a ±8.54	17.31 ^a ±0.20
Termites 5%	20.67 ^c ±2.08	15.00 ^b ±5.00	25.00 ^b ±9.00	29.00 ^b ±12.53	9.00 ^b ±0.00	14.33 ^b ±6.03	17.34 ^a ±0.19
Termite 10%	39.67 ^d ±1.53	19.50 ^b ±6.38	40.00 ^b ±2.65	35.33 ^c ±4.51	18.33 ^c ±4.16	16.33 ^b ±11.59	17.60 ^b ±0.16
<i>Gynanisa</i> 5%	9.00 ^{ba} ±0.87	25.33 ^b ±4.91	11.17 ^b ±1.15	26.67 ^b ±12.41	18.00 ^b ±3.46	19.67 ^b ±3.18	17.90 ^b ±0.51
<i>Gynanisa</i> 10%	32.00 ^d ±3.00	35.00 ^c ±2.00	18.17 ^c ±9.00	23.33 ^b ±14.19	32.67 ^c ±2.52	27.33 ^c ±14.22	18.29 ^c ±0.58
Mopane 5%	12.39 ^{cb} ±8.41	27.83 ^b ±7.59	4.67 ^b ±2.08	20.66 ^b ±19.04	12.00 ^b ±6.00	27.33 ^c ±22.81	18.00 ^b ±0.46
Mopane 10%	28.67 ^c ±2.08	39.00 ^c ±4.36	26.33 ^c ±6.82	29.33 ^b ±6.81	18.33 ^b ±6.81	25.67 ^c ±20.26	18.52 ^c ±0.94
Thin porridge	Protein	Fat	ADF	NDF	Ash	Moisture	Energy
Control	5.67 ^a ±1.53	2.00 ^a ±1.00	18.67 ^a ±4.16	11.33 ^a ±7.23	2.00 ^a ±1.00	11.33 ^a ±5.13	13.79 ^a ±0.51
Termites 5%	22.67 ^c ±2.08	7.67 ^b ±4.04	28.50 ^b ±11.03	22.83 ^b ±10.25	25.67 ^b ±2.08	16.00 ^b ±8.19	16.91 ^b ±0.81
Termite 10%	39.33 ^c ±2.52	15.50 ^b ±9.34	37.00 ^b ±3.61	34.00 ^c ±4.00	30.67 ^c ±3.51	29.67 ^c ±6.03	17.18 ^b ±0.26
<i>Gynanisa</i> 5%	14.17 ^b ±1.26	16.67 ^b ±10.02	21.00 ^b ±12.12	12.00 ^b ±8.19	26.33 ^b ±9.29	26.67 ^c ±8.02	17.60 ^b ±0.76
<i>Gynanisa</i> 10%	22.33 ^c ±15.82	29.67 ^c ±9.71	25.00 ^c ±3.61	17.50 ^b ±9.99	39.67 ^c ±2.08	21.33 ^b ±14.22	17.91 ^c ±0.86
Mopane 5%	12.83 ^b ±2.36	23.33 ^b ±6.66	10.33 ^b ±12.10	5.67 ^b ±1.53	28.00 ^b ±15.39	26.67 ^c ±13.32	17.31 ^b ±1.51
Mopane 10%	32.33 ^c ±2.08	36.33 ^c ±5.51	27.83 ^c ±13.29	23.67 ^d ±9.07	35.00 ^{bc} ±5.57	24.67 ^b ±19.86	18.23 ^c ±0.71

Values presented are means ± standard deviations, Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05).

Appendix 3.3: Effect of edible insects on essential amino acids composition (g/100g) of thin porridge fortified with edible insects

Crumbly porridge	Histidine	Threonine	Lysine	Tryptophan	Methionine	Valine	Leucine	Phenylalanine
Control	0.19 ^a ±0.01	0.27 ^a ±0.03	0.13 ^a ±0.00	0.22 ^a ±0.02	0.26 ^a ±0.03	0.32 ^a ±0.03	1.11 ^a ±0.03	0.42 ^a ±0.04
Termites 5%	0.27 ^a ±0.03	0.31 ^a ±0.07	0.26 ^a ±0.12	0.38 ^a ±0.03	0.32 ^a ±0.02	0.46 ^{bc} ±0.04	1.21 ^a ±0.07	0.54 ^a ±0.02
Termite 10%	0.34 ^b ±0.07	0.44 ^b ±0.07	0.31 ^a ±0.01	0.56 ^b ±0.05	0.32 ^a ±0.05	0.60 ^{bd} ±0.00	1.36 ^a ±0.08	0.62 ^b ±0.02
<i>Gynanisa</i> 5%	0.29 ^a ±0.02	0.35 ^a ±0.03	0.34 ^b ±0.06	0.36 ^a ±0.07	0.32 ^a ±0.03	0.44 ^a ±0.04	1.26 ^a ±0.07	0.55 ^a ±0.07
<i>Gynanisa</i> 10%	0.31 ^b ±0.05	0.42 ^b ±0.09	0.40 ^b ±0.14	0.49 ^a ±0.10	0.33 ^a ±0.03	0.51 ^b ±0.07	1.34 ^a ±0.14	0.59 ^b ±0.06
Mopane 5%	0.30 ^{ab} ±0.02	0.31 ^a ±0.03	0.22 ^a ±0.03	0.38 ^a ±0.14	0.30 ^a ±0.04	0.39 ^a ±0.04	1.15 ^a ±0.18	0.54 ^a ±0.09
Mopane 10%	0.32 ^b ±0.03	0.41 ^b ±0.06	0.38 ^b ±0.10	0.61 ^b ±0.09	0.35 ^a ±0.03	0.53 ^b ±0.07	1.29 ^a ±0.14	0.66 ^b ±0.05
Thin porridge	Histidine	Threonine	Lysine	Tryptophan	Methionine	Valine	Leucine	Phenylalanine
Control	0.23 ^a ±0.02	0.28 ^a ±0.08	0.13 ^a ±0.01	0.33 ^a ±0.16	0.21 ^a ±0.04	0.35 ^a ±0.07	1.33 ^a ±0.14	0.55 ^a ±0.07
Termites 5%	0.27 ^a ±0.01	0.36 ^b ±0.02	0.27 ^a ±0.06	0.61 ^b ±0.08	0.34 ^b ±0.02	0.53 ^b ±0.06	1.40 ^a ±0.09	0.58 ^a ±0.06
Termite 10%	0.34 ^b ±0.04	0.46 ^c ±0.06	0.35 ^b ±0.01	0.63 ^b ±0.12	0.37 ^b ±0.01	0.63 ^b ±0.00	1.48 ^a ±0.06	0.62 ^b ±0.03
<i>Gynanisa</i> 5%	0.29 ^a ±0.03	0.34 ^b ±0.04	0.24 ^a ±0.03	0.46 ^b ±0.14	0.33 ^b ±0.03	0.46 ^a ±0.02	1.27 ^a ±0.08	0.58 ^a ±0.06
<i>Gynanisa</i> 10%	0.31 ^b ±0.07	0.43 ^b ±0.04	0.44 ^c ±0.03	0.56 ^b ±0.13	0.34 ^b ±0.03	0.59 ^b ±0.05	1.38 ^a ±0.06	0.60 ^b ±0.08
Mopane 5%	0.30 ^{ab} ±0.02	0.33 ^b ±0.04	0.23 ^a ±0.05	0.62 ^b ±0.07	0.41 ^c ±0.03	0.47 ^a ±0.01	1.41 ^a ±0.08	0.64 ^b ±0.03
Mopane 10%	0.34 ^b ±0.02	0.42 ^c ±0.04	0.38 ^b ±0.05	0.67 ^b ±0.07	0.39 ^b ±0.03	0.52 ^b ±0.06	1.41 ^a ±0.16	0.63 ^b ±0.07

Values are presented as means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05).

Appendix 3.4: Effect of edible insects on non-essential amino acids composition (g/100g) in thin and crumbly porridge fortified with edible insects

Crumbly porridge	Arginine	Serine	Glycine	Asparagine	Glutamine	Alanine	Proline
Control	0.24 ^a ±0.06	0.37 ^a ±0.01	0.25 ^a ±0.02	0.40 ^a ±0.03	1.50 ^a ±0.12	0.59 ^a ±0.02	0.74 ^a ±0.03
Termites 5%	0.36 ^b ±0.03	0.41 ^a ±0.06	0.38 ^a ±0.03	0.55 ^a ±0.10	1.48 ^a ±0.26	0.78 ^b ±0.06	0.84 ^a .05
Termite 10%	0.52 ^b ±0.02	0.54 ^b ±0.02	0.48 ^a ±0.02	0.73 ^b ±0.01	1.86 ^b ±0.06	0.99 ^b ±0.04	0.93 ^a ±0.10
<i>Gynanisa</i> 5%	0.39 ^b ±0.03	0.46 ^a ±0.07	0.40 ^a ±0.02	0.63 ^{ab} ±0.07	1.70 ^b ±0.16	0.72 ^b ±0.01	0.84 ^a ±0.01
<i>Gynanisa</i> 10%	0.40 ^b ±0.11	0.55 ^b ±0.07	0.47 ^b ±0.10	0.76 ^a ±0.19	1.87 ^b ±0.23	0.82 ^b ±0.18	0.95 ^a ±0.12
Mopane 5%	0.31 ^a ±0.01	0.43 ^a ±0.06	0.36 ^a ±0.06	0.56 ^a ±0.06	1.46 ^a ±0.17	0.63 ^a ±0.11	0.77 ^a ±0.12
Mopane 10%	0.45 ^b ±0.06	0.50 ^b ±0.07	0.49 ^b ±0.06	0.75 ^b ±0.16	1.75 ^b ±0.27	0.73 ^b ±0.10	0.86 ^a ±0.10
Thin porridge	Arginine	Serine	Glycine	Asparagine	Glutamine	Alanine	Proline
Control	0.24 ^a ±0.06	0.43 ^a ±0.05	0.30 ^a ±0.10	0.46 ^a ±0.08	1.54 ^a ±0.27	0.65 ^a ±0.08	0.87 ^a ±0.10
Termites 5%	0.40 ^b ±0.05	0.43 ^a ±0.03	0.43 ^a ±0.07	0.64 ^a ±0.07	1.82 ^a ±0.06	0.94 ^a ±0.17	0.99 ^a ±0.14
Termite 10%	0.54 ^b ±0.01	0.56 ^b ±0.03	0.53 ^b ±0.01	0.77 ^b ±0.06	1.93 ^a ±0.11	1.08 ^b ±0.05	1.09 ^a ±0.08
<i>Gynanisa</i> 5%	0.35 ^a ±0.03	0.49 ^a ±0.07	0.39 ^a ±0.02	0.64 ^a ±0.04	1.68 ^a ±0.19	0.72 ^a ±0.05	0.86 ^a ±0.07
<i>Gynanisa</i> 10%	0.49 ^b ±0.10	0.56 ^b ±0.03	0.49 ^b ±0.09	0.87 ^b ±0.07	1.92 ^a ±0.14	0.88 ^a ±0.05	0.96 ^a ±0.07
Mopane 5%	0.38 ^a ±0.03	0.50 ^a ±0.03	0.40 ^a ±0.02	0.60 ^a ±0.09	1.65 ^a ±0.21	0.75 ^a ±0.07	0.95 ^a ±0.07
Mopane 10%	0.42 ^b ±0.03	0.57 ^b ±0.05	0.47 ^b ±0.06	0.80 ^b ±0.14	1.93 ^a ±0.25	0.81 ^a ±0.12	1.00 ^a ±0.15

Values are presented as means ± standard deviations. Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.05).

Appendix 3.5: Effect of edible insects on mineral composition in thin and crumbly porridge fortified with edible insects

Crumbly porridge	Calcium	Phosphorus	Magnesium	Sodium	Potassium	Iron	Copper	Zinc	Manganese
	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
Control	10.83 ^a ±6.25	12.63 ^a ±7.49	16.00 ^a ±9.00	14.50 ^a ±6.76	21.50 ^a ±14.91	12.17 ^a ±3.01	10.50 ^a ±0.00	10.00 ^a ±4.25	13.33 ^a ±0.00
Termites 5%	15.00 ^a ±10.33	19.83 ^a ±17.06	22.00 ^b ±10.39	18.67 ^b ±8.61	24.50 ^a ±13.94	18.13 ^b ±9.83	13.83 ^b ±5.77	13.83 ^d ±7.83	18.67 ^b ±12.79
Termite 10%	29.17 ^b ±13.57	28.33 ^b ±11.84	32.67 ^b ±8.08	28.50 ^b ±14.91	34.50 ^a ±8.35	20.17 ^b ±8.08	29.33 ^b ±8.52	27.67 ^b ±5.75	28.17 ^b ±10.75
<i>Gynanisa</i> 5%	22.00 ^b ±3.46	16.50 ^b ±8.66	19.00 ^a ±10.39	18.33 ^b ±11.02	18.17 ^b ±6.35	16.67 ^b ±17.16	30.50 ^b ±17.32	22.00 ^b ±0.00	19.50 ^b ±10.39
<i>Gynanisa</i> 10%	19.83 ^a ±6.25	19.50 ^b ±12.12	19.33 ^a ±16.17	22.50 ^b ±8.66	22.50 ^b ±12.62	35.33 ^c ±3.18	23.67 ^b ±11.62	27.17 ^b ±17.90	29.50 ^b ±17.97
Mopane 5%	12.33 ^a ±11.84	22.00 ^b ±11.26	22.00 ^b ±10.39	13.00 ^b ±7.94	21.83 ^b ±10.38	17.17 ^b ±16.66	13.83 ^b ±5.77	11.17 ^d ±10.10	16.17 ^a ±9.07
Mopane 10%	24.67 ^b ±20.88	27.83 ^b ±14.84	22.00 ^b ±10.39	20.83 ^b ±14.18	19.50 ^b ±14.03	33.83 ^c ±5.39	4.83 ^c ±4.91	35.33 ^c ±7.01	17.50 ^a ±11.84
Thin porridge	Calcium	Phosphorus	Magnesium	Sodium	Potassium	Iron	Copper	Zinc	Manganese
	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
Control	18.13 ^a ±6.25	10.50 ^a ±6.06	16.00 ^a ±10.39	18.17 ^a ±14.77	15.00 ^a ±10.26	10.50 ^a ±10.05	26.00 ^a ±2.00	14.33 ^a ±17.98	26.50 ^a ±10.15
Termites 5%	19.33 ^a ±16.37	14.00 ^a ±9.64	13.00 ^{ab} ±13.75	18.67 ^a ±8.61	6.83 ^d ±6.93	22.33 ^b ±7.23	28.50 ^a ±9.18	16.83 ^a ±15.33	22.67 ^b ±14.06
Termite 10%	19.83 ^a ±17.50	18.00 ^a ±6.06	16.00 ^{ab} ±10.39	21.00 ^b ±14.91	14.83 ^{ab} ±13.71	22.83 ^b ±12.53	31.83 ^a ±9.93	23.67 ^b ±12.05	33.00 ^b ±4.09
<i>Gynanisa</i> 5%	26.17 ^b ±11.00	28.67 ^b ±11.18	22.00 ^b ±10.39	19.67 ^b ±15.18	18.17 ^b ±15.14	18.67 ^b ±19.66	28.17 ^a ±4.25	16.67 ^a ±11.56	18.00 ^a ±19.91
<i>Gynanisa</i> 10%	14.50 ^a ±15.59	22.00 ^b ±15.76	26.00 ^b ±15.10	21.67 ^b ±19.32	22.83 ^b ±15.14	25.83 ^b ±7.27	10.50 ^b ±0.00	22.83 ^b ±11.72	10.17 ^a ±6.35
Mopane 5%	26.67 ^b ±19.94	31.00 ^b ±9.76	26.33 ^b ±15.57	28.83 ^b ±16.16	28.00 ^b ±13.26	17.17 ^b ±21.68	22.67 ^a ±20.03	29.50 ^c ±19.94	22.50 ^b ±20.57
Mopane 10%	33.00 ^b ±7.26	32.50 ^b ±9.73	28.67 ^b ±16.17	37.00 ^b ±2.65	32.83 ^b ±10.73	29.50 ^c ±1.80	26.83 ^a ±14.36	30.00 ^c ±4.33	25.33 ^b ±8.28

Values presented are means ± standard deviations Means marked by different letters in the same column are significantly different, according to the Tukey HSD test (p<0.0)